Promotion of Biogas Plant Application in the Mekong Delta of Vietnam

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ABSTRACT

The study focuses on waste management in the Mekong Delta of Vietnam (MD) through the application of biogas plants to livestock and agricultural waste treatment. As the biggest "rice bowl" in the country, the MD produces more than 50% of the national aqua-agricultural production, in which livestock sector contributes more than 20% of agricultural growth. The increasing livestock sector, however, has been attributed to the environmental problems, particularly in relation to the free discharge of waste/wastewater into the water open sources in the region. Such the environmental problems have become more serious in the rural areas of the MD where the water from the canal network is used as the main water supply sources to the 60% of local communities. Biogas technology was introduced as an environmentally-friendly treatment for animal and human wastes in the MD in the 1980s. Nonetheless, the number of biogas plants already constructed is considerably limited in comparison to the actual demand on livestock waste treatment in the region. The study, therefore, aims at seeking for possible solutions to promote the widespread application of biogas plants in the MD in order to help improve the sanitary condition of the local communities.

In this study, a survey of 110 farmers was conducted in the three provinces of the MD. The farmers included biogas user households, non-biogas user households, and biogas masons. The interviews with the three groups of farmers provided profound and comprehensive information on the actual application and demand of biogas plants in the MD. Accordingly, a large number of the local people have acknowledged the great benefits of biogas application. However, the interviews revealed that there are some impediments to the development of biogas plants in the region such as high investment cost, shortage of input to biogas plants, and limited possibilities of application of by-products from biogas plants.

In an attempt to search for locally available materials to be used as additional inputs to pig manure (PM) in biogas plants, water hyacinth (WH) and spent mushroom compost (SMC) were chosen due to their potentials and availability. The testing results showed that co-digestion of PM with either WH or SMC maintained the quality and quantity of produced biogas very well. The batch experiments of the PM+WH co-digestion indicated that the more percentage of WH containing in the feeding rate, the more biogas will be produced. The produced biogas was not significantly different between the treatment of 100%PM+ 0%SMC, of 75%PM+25%SMC, of 50%PM+50%SMC, and of 25%PM+75%SMC. In both of the cases, the produced biogas was in good quality with methane content reaching up to 60%. More significantly, the semi-continuous treatment of 75%PM+25%WH and of 75%PM+25%SMC were in good operation during a 90 consecutive day period without a blockage of the substrate even though the substrate was not agitated.

In addition to the high potentials of WH and SMC as the additional materials, the bio-slurries from the co-digesters had a positive response to cultivation and aquaculture. In the tests on the growth of leaf mustard fertilized separately with the bio-slurries from the different kinds of co-digestion plants (the plant fed solely with PM, with PM+WH, and with PM+SMC) and inorganic fertilizer (IF), the weight of the plant was not significantly different in the treatment of IF, of PM, and of PM+WH. The weight of the mustard fed with the bio-slurry from the PM+SMC co-digester was bigger than the others. By application of the bio-slurries into the fishpond, the growing weight of the fish was not significantly different from the treatment of PM, of PM+WH, and of PM+SMC.

In the study, a new HDPE digester was developed and worked considerably well in the treatment of pig manure at the farming household. The testing results showed that this HDPE digester can make a relatively efficient treatment and produce biogas with significantly good quality. The gas pressure produced by the new design is high enough for cooking as well as for lighting purpose. More importantly, the new model has been designed for a more reasonable and affordable investment cost.

Based on the positive results of the study, WH and SMC are highly recommended as additional materials potentially applicable for biogas plants in the MD. Farmers now have alternative models of biogas plants as well as choices of additional materials for their biogas plants. They can confidently invest in the installation of a biogas plant with little fear of the shortage of pig manure and with reasonable investment cost. Additionally, the bio-slurry of the co-digesters could be applied positively to vegetable planting and fishery, helping farmers generate more income and being engaged in sustainable farming.

Zusammenfassung

Die vorliegende Arbeit beschäftigt sich mit der Nutzung von Biogasanlagen zur Verwertung von tierischen und landwirtschaftlichen Abfällen im Mekong-Delta (MD) in Vietnam. Als größte "Reisschüssel" des Landes werden im MD mehr als 50% der agrarwirtschaftlichen Erzeugnisse produziert, über 20% werden dabei von der stetig wachsenden Viehwirtschaft eingenommen. Die zunehmende Viehhaltung im MD trägt jedoch auch zu ökologischen Problemen in der Region bei, insbesondere die Einleitung von tierischen Abfällen und Abwässern in offene Gewässer und die Kanalsysteme ist als problematisch einzustufen. Gerade in den ländlichen Gebieten des MD, in denen das Wasser aus dem Kanalsystem direkt zur Wasserversorgung der örtlichen Gemeinden genutzt wird, sind die Umweltprobleme durch die Viehhaltung gravierend.

Die Biogas-Technologie wurde bereits in den 1980er Jahren als eine umweltfreundliche Behandlung von tierischen und menschlichen Abfällen im MD eingeführt. Dennoch ist die Zahl der bereits errichteten Biogasanlagen im Vergleich zu dem tatsächlichen Bedarf zur Behandlung der vorhandenen viehwirtschaftlichen Abfallprodukte in der Region begrenzt. Das Ziel dieser Arbeit ist es daher, geeignete Lösungen und Anwendungsmöglichkeiten für Biogasanlagen zu finden, die eine Verbreitung im MD ermöglichen und dabei die sanitären Verhältnisse in den Gemeinden vor Ort verbessern.

Als Teil der vorliegenden Arbeit wurde eine Befragung von 110 Landwirten in den drei Provinzen des MD durchgeführt. Die befragten Landwirte wurden in folgende Kategorien eingeteilt: Biogas nutzende Haushalte, Haushalte ohne Biogasnutzung und Biogasanlagenbauer. Die Interviews mit den drei Gruppen von Landwirten lieferten umfangreiche und tiefgreifende Informationen zur tatsächlichen Nutzung von Biogas und dem benötigten Bedarf an Biogasanlagen im MD. Demzufolge hat ein Großteil der örtlichen Bevölkerung die bedeutenden Vorteile der Biogasnutzung erkannt. Dem Bau von weiteren Biogasanlagen stehen aber eine Vielzahl an Hindernissen, wie z.B. die zu hohen Investitionskosten, der Mangel an geeignetem Substrat oder die begrenzten Möglichkeiten der Nutzung von Gärresten, die beim Betrieb von Biogasanlagen anfallen, gegenüber.

Bei dem Bestreben möglichst lokal verfügbare Materialien als Substrate für die Biogasanlagen zu verwenden, wurden für die durchzuführenden Versuche aufgrund ihrer hohen Biogaspotenziale und ihrer regionalen Verfügbarkeit Schweinegülle (PM), Wasserhyazinthe (WH) und Pilzkompost (SMC) ausgewählt. Die Versuchsergebnisse zeigen, dass die Co-Vergärung von PM entweder mit WH oder mit SMC als Zuschlagstoffe gute Ergebnisse in der Qualität und der Quantität des produzierten Biogases ergeben. Dies wird auch durch die Resultate der Co-Vergärung von PM und WH in den Batch-Ansätzen bestätigt, je höher der Prozentsatz von WH am Mischungsverhältnis, desto

mehr Biogas wird produziert. Bei dem erzeugten Biogas der Mischungsverhältnisse 100%PM+0%SMC, 75%PM+25%SMC, 50% PM+50%SMC und 25%PM+75%SMC kann kein signifikanter Unterschied abgeleitet werden. In allen Versuchsvarianten war das produzierte Biogas von guter Qualität und wies einem Methangehalt von bis zu 60 Vol.-% auf. Bei den semi-kontinuierlichen Versuchsreihen mit Mischungsverhältnissen von 75%PM+25%WH und 75%PM+25%SMC konnte in einem Zeitraum von 90 Tagen ein stabiler Betrieb der Versuchsanlagen ohne Verblockungen durch die Substrate gewährleistet werden, obwohl die Substrate nicht vorab gemischt wurden.

Zusätzlich zu dem hohen Biogaspotential von WH und SMC haben die ausgewählten Zuschlagstoffe auch als Gärsubstrate nach der Co-Vergärung einen positiven Effekt auf den landwirtschaftlichen Anbau und die Aquakultur. Während der Wachstumsuntersuchungen der braunen Senfpflanze (*Brassica juncea*) mit den unterschiedlichen Gärsubstraten aus der Co-Vergärung (Biogasanlagebeschickung nur mit PM, mit PM+WH und PM+SMC) konnte im Vergleich zu Mineraldüngemitteln (IF) kein signifikanter Unterschied bei dem Gewicht der Senfkörner festgestellt werden. Nur bei der Düngung mit dem Gärsubstrat aus PM+SMC waren die Senfsamen deutlich schwerer als bei der Düngung mit den anderen Gärresten. Bei der Fischfutterbeimischung von PM-, PM+WH- und PM+SMC-Gärresten in Fischteichen konnte ebenfalls keine signifikante Abweichung im Wachstum oder im Gewicht der Fische nachgewiesen werden.

Der während der Untersuchungen entwickelte Fermenter aus HDPE bewährte sich vor allem in der Behandlung von Schweinegülle aus den landwirtschaftlichen Betrieben. Die Versuchsergebnisse zeigen, dass mit diesem HDPE-Fermenter eine effiziente Behandlung der Schweinegülle möglich ist und zudem eine gute Biogasqualität erzeugt wird. Der Gasdruck, der in diesem neuen HDPE-Fermenter entsteht, ist hoch genug, um das Biogas zum Kochen sowie zur Beleuchtung zu nutzen. Zudem bewegen sich die Investitionskosten für das neue Fermentermodel im Vergleich zu den am Markt erhältlichen Fermentern in einem finanziell tragbaren und zumutbaren Rahmen.

Aufgrund der positiven Versuchsergebnisse dieser Arbeit können sowohl WH als auch SMC als Zuschlagstoffe für die Co-Vergärung in Biogasanlagen für das MD empfohlen werden. Die Landwirte haben nun eine alternative Biogasanlagenvariante sowie eine Bandbreite an geeigneten regionalen Zuschlagstoffen für den Betrieb der Biogasanlagen. Die Investition in eine Biogasanlage kann von den Landwirten mit tragbaren finanziellen Kosten und ohne Angst vor einem Mangel an Schweinegülle erfolgen. Darüber hinaus können die Gärsubstrate aus der Co-Vergärung von den Landwirten zur Düngung von Gemüsebeeten sowie in der Aquakultur eingesetzt werden, um ein höheres Einkommen zu erzielen und es wird damit gleichzeitig ein Schritt in Richtung auf eine nachhaltige Landwirtschaft gemacht.

TÓM TẮT

Đây là một nghiên cứu về quản lý chất thải rắn ở ĐBSCL thông qua sử dụng hầm ủ biogas để xử lý chất thải chăn nuôi và chất thải nông nghiệp. Được biết như vựa lúa của cả nước, hàng năm ĐBSCL sản xuất trên 50% tổng sản lượng nông nghiệp và thủy sản, trong đó chăn nuôi chiếm đến 20% sản xuất nông nghiệp. Hoạt động chăn nuôi gây ra tình trạng ô nhiễm môi trường do người chăn nuôi thường xả trực tiếp chất thải / nước thải vào hệ thống kênh rạch. Tình trạng ô nhiễm môi trường ngày càng trở nên nghiêm trọng hơn khi có trên 60% dân cư nông thôn ĐBSCL sử dụng nước từ kênh rạch cho sinh hoạt hàng ngày. Công nghệ biogas đã được giới thiệu là một biện pháp thân thiện môi trường trong xử lý chất thải chăn nuôi và chất thải sinh hoạt ở ĐBSCL từ những năm 1980. Tuy nhiên số lượng hầm ủ đang có vẫn chưa tương xứng với nhu cầu xử lý chất thải hiện tại của các hộ chăn nuôi. Nghiên cứu này đề xuất những giải pháp triển khai hầm ủ biogas trên diện rộng để cải thiện điều kiện vệ sinh tại cộng đồng địa phương.

Trước tiên một cuộc khảo sát tại 110 hộ dân đã được tiến hành ở 3 tỉnh thành ĐBSCL. Các hộ dân khảo sát bao gồm hộ có hầm ủ biogas, hộ chưa có hầm ủ biogas, và thợ xây hầm ủ. Kết quả phỏng vấn ở cả ba nhóm hộ đã cung cấp những thông tin bổ ích về hiện trạng sử dụng hầm ủ biogas và nhu cầu của chúng tại vùng ĐBSCL. Đa số các hộ dân đều đánh giá cao lợi ích to lớn của hầm ủ biogas. Tuy nhiên cuộc khảo sát cũng xác định được một số rào cản trong quá trình phát triển hầm ủ biogas như chi phí đầu tư tốn kém, thiếu hụt nguyên liệu nạp cho hầm ủ, hạn chế trong khai thác chất thải đầu ra của hầm ủ…

Trong quá trình tìm kiếm nguồn nguyên liệu địa phương làm nguyên liệu nạp cho hầm ủ bên cạnh phân heo (PM), lục bình (WH) và rơm sau ủ nấm (SMC) được chọn thử nghiệm. Kết quả thử nghiệm cho thấy trong cả hai trường hợp ủ kết hợp PM+WH và PM+SMC, lượng biogas thu được có năng suất và chất lượng tốt. Thí nghiệm ủ yếm khí theo mẻ kết hợp PM+WH ghi nhận năng suất biogas tăng nếu tăng phần trăm lục bình trong hỗn hợp. Thí nghiệm ủ yếm khí theo mẻ PM+SMC không ghi nhận khác biệt có ý nghĩa giữa các nghiệm thức 100%PM+0%SMC, 75%PM+25%SMC, 50%PM+50%SMC và 25%PM+ 75%SMC. Trong cả hai trường hợp, khí gas thu được có chất lượng tốt với hàm lượng mê-tan đạt gần 60%. Đặc biệt thí nghiệm ủ yếm khí bán liên tục các hỗn hợp 75%PM+ 25%WH và 75%PM+ 25%SMC vận hành ổn định trong 90 ngày không bị tắc nghẽn mặc dù không khuấy đảo.

Bên cạnh đó, nghiên cứu cũng ghi nhận hiệu quả của việc sử dụng bùn thải từ quá trình ủ kết hợp cho trồng trọt và nuôi cá. Trong thí nghiệm trồng cây cải xanh với những nguồn phân bón khác nhau (bón phân vô cơ IF, bón bùn thải từ hầm ủ với nguyên liệu nạp là PM, PM+WH và PM+SMC), năng suất cây trồng không khác biệt có ý nghĩa giữa các nghiệm thức IF, PM, và PM+WH; tuy nhiên năng suất của cây cải có bón bùn thải từ hầm ủ nạp

PM+SMC lại cao hơn hẳn. Khi bón các loại bùn thải vào ao nuôi cá, năng suất cá không khác biệt có ý nghĩa giữa các nghiệm thức nạp PM, PM+WH, và PM+SMC.

Cũng trong nghiên cứu này, một mô hình túi ủ mới bằng vải nhựa HDPE đã được phát triển và ứng dụng thành công để xử lý chất thải chăn nuôi hộ gia đình. Kết quả phân tích một số thông số ô nhiễm đầu ra cho thấy hiệu quả xử lý của túi ủ mới ngang bằng với các hầm ủ hiện có ở ĐBSCL, đồng thời chất lượng khí gas sinh ra tốt. Áp suất khí gas từ túi ủ mới đủ để phục vụ thắp sáng. Quan trọng nhất là giá thành của túi ủ mới có thể được người dân dễ dàng chấp nhận.

Với các kết quả ghi nhận, WH và SMC được đề nghị sử dụng làm nguồn nguyên liệu nạp bổ sung cho các hầm ủ biogas ở ĐBSCL. Như vậy người dân sẽ có nhiều lựa chọn về nguyên liệu nạp cho hầm ủ biogas. Họ đã có thể mạnh dạn xây dựng một hầm ủ biogas mà không phải e ngại về sự thiếu hụt nguyên liệu nạp hay chi phí đầu tư cao. Ngoài ra họ cũng có thể sử dụng bùn thải từ hầm ủ làm nguồn phân bón hiệu quả cho trồng vườn hoặc nuôi cá trong mô hình canh tác bền vững để làm tăng thu nhập cho hộ gia đình.

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ABBREVIATIONS

ACRSP : Aquaculture Collaborative Research Support Program

APHA : American Public Health Association

BfdW : Brot für die Welt

BOD5 : biological oxygen demand in 5 days

C/N ratio : carbon-to-nitrogen ratio

CD : cattle dung

CDM : clean development mechanism

CEERE : Center of Environmental Engineering and Renewable Energy

CF : commercial food

COD : chemical oxygen demand

CPHCSC : Central Population and Housing Census Steering Committee

DANIDA : Danish International Development Assistance

DLP : Department of Livestock Production

DM : dry matter

EEP : Energy and Environment Partnership Mekong

FAO : Food and Agriculture Organization

GTZ : Deutsche Gesellschaft für Technische Zusammenarbeit

GSO : Vietnam's General Statistical Office

HDPE : high-density polyethylene

IF : inorganic fertilizer

LCA : life cycle assessment

LPG : liquid petroleum gas

MD : Mekong Delta

MONRE : Vietnam's Ministry of Natural Resources and Environment

MPN : most probable number

O&M : operation and maintenance

ODM : organic dry matter

PE : polyethylene

PL : poultry litter

PM : pig manure

PRRS : porcine reproductive and respiratory syndrome

PVC : polyvinyl chloride

REC : Renewable Energy Center

RS : rice straw

SANSED : project on Closing Nutrient Cycles in Decentralized Water Treatment Systems in the Mekong Delta, Vietnam

SidaSAREC : Swedish International Development Co-operation Agency

SMC : spent mushroom compost

SNV : project on Vietnam Biogas Program for the Animal Husbandry Sector

TG-BP : Thailand Germany Biogas Program

TKN : total Kjeldahl nitrogen

TP : total phosphorus

TPD : project on Promote the commercialization of the TG-BP biogas plant

TS : total solids

USD : United State dollar (currency)

UV : ultraviolet

VAC : the farming system on garden - fishpond - animal husbandry

VAC : the farming system on garden - fishpond - animal husbandry - biogas

VIE020 : project on Sustainable Production of Aqua-agriculture and Using Renewable Energy from Water Hyacinth and Waste

VND : Vietnamese Dong (currency)

VSS : volatile suspended solids

WB : World Bank

WH : water hyacinth

CHAPTER 1. INTRODUCTION

The study focuses on waste management in the Mekong Delta of Vietnam (MD) through the application of biogas plants to livestock and agricultural wastes treatment. The MD, a "rice bowl" of Vietnam, produces more than 50% of the national aqua-agricultural production every year, in which the livestock production constitutes more than 20% of the agriculture growth in the MD. The expansion and increase in the livestock sector, on the other hand, has been attributed to the local environmental problems, particularly in relation to the free discharge of waste/wastewater into water open sources in the region. Such the environmental problems have become significantly serious in the rural areas where the water from the canal network is used as the main water supply sources to the local communities. To help partly solve these problems, biogas technology was introduced as an environmentally-friendly treatment for not only animal waste but also human waste in the MD in the 1980s. However, the number of biogas plants already constructed in the MD is considerably limited in comparison to the actual demand on livestock waste treatment in the region. There are some major reasons for the limited biogas development such as high investment cost, shortage of input to biogas plants, and limited application of by-products from biogas plants. The study is, therefore, aimed at seeking for possible solutions to promote the widespread application of biogas technology in the MD in order to help improve sanitary conditions of the local communities in the region.

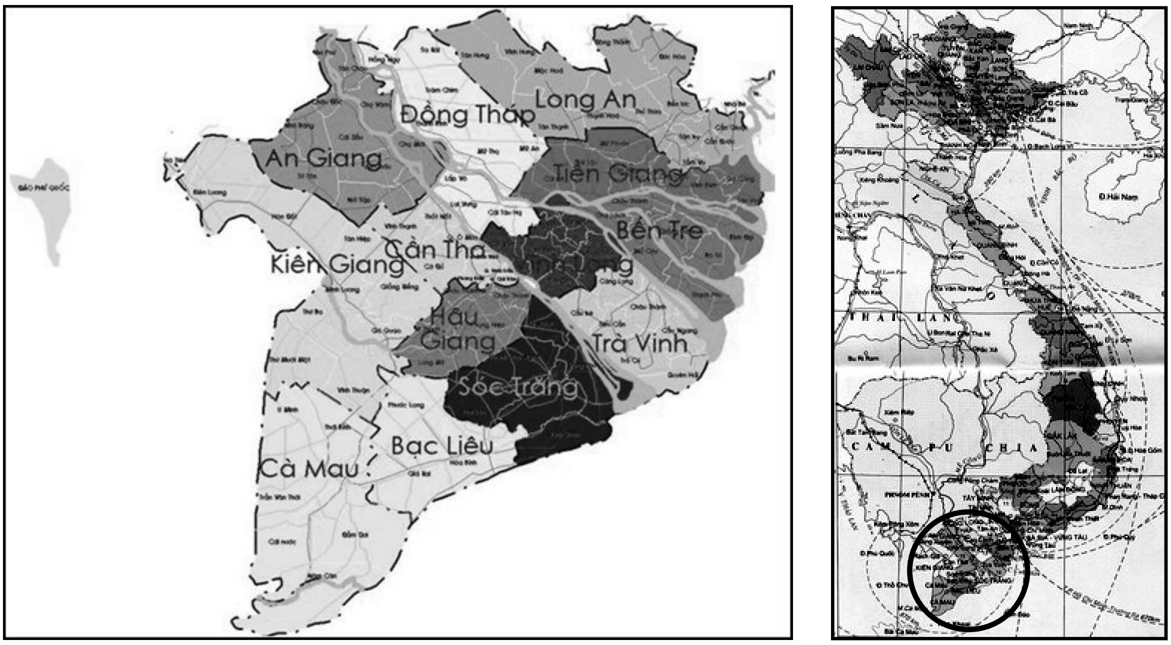


Fig 1.1 Map of the MD (left) in reference with Vietnam (right)

1.1 BIOGAS APPLICATION IN THE MEKONG DELTA

1.1.1 Livestock production in the Mekong Delta

Aqua-agriculture production has developed rapidly in recent years in the MD, becoming the biggest aqua-agriculture production area in Vietnam. As a vital sector of agricultural production in Vietnam in general and in the MD in particular, livestock husbandry makes up about 10% of the agricultural production in Vietnam. The average growth rate of the livestock sector has been about 20% in the past ten years.

The livestock sector consists primarily of pig production [Nguyen and Vo, 2008]. In fact, pigs account for more than 90% of the total livestock in terms of living weight in Vietnam (Fig 1.2). As a result, pig manure is a main input material fed into biogas plants. In this regard, Tran *et al.* (2009) reported that more than 90% of the biogas user households apply pig manure as the sole input material to their biogas plants in the survey areas of the project Vietnam Biogas Program for the Animal Husbandry Sector (SNV).

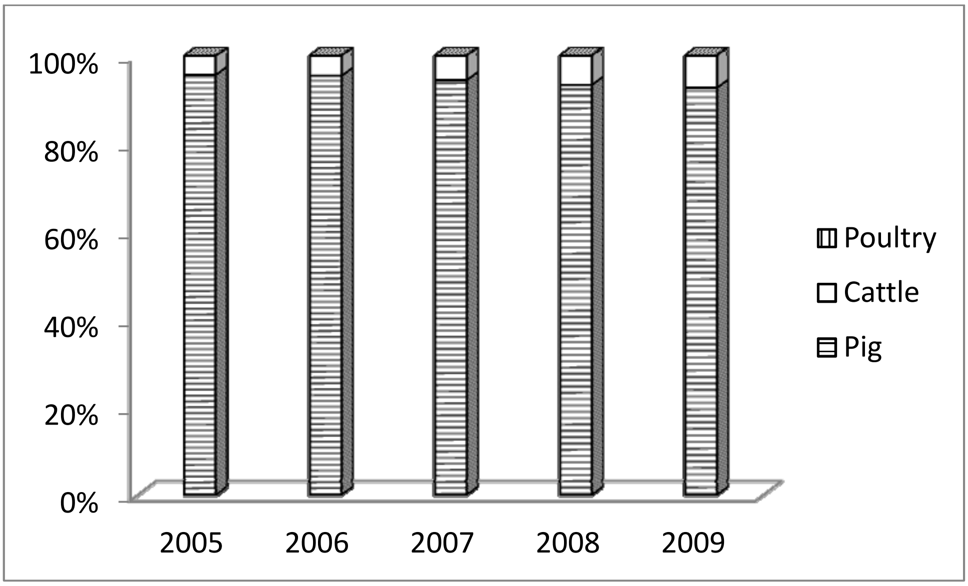


Fig 1.2 Living weight of main livestock in Vietnam by year

Vietnam has made a long-term development strategy for livestock sector in which livestock husbandry has increasingly played an important role in agricultural production. According to the Vietnam's Livestock Development Strategy until 2020, the livestock proportion in agriculture will reach 32% by 2010, increasing up to 38% and 42% by 2015 and 2020, respectively [DLP, 2007]. The growth of the livestock sector possibly makes positive impacts on income generation, job opportunity and living standard of the people in rural Vietnam, especially the farmers living in the remote and less developed areas. It also helps develop agricultural product processing as well as shift labor force in agriculture. Conversely, the livestock development has some negative impacts on the local environment unless there are some effective mechanisms to deal with livestock wastes.

The wastes coming from animal husbandry units, slaughterhouses, and meat-processing factories are potential causes to air or soil pollution and water sources pollution. More seriously, most of the livestock waste and wastewater are freely discharged into open water bodies with very limited pre-treatment in the MD. In the meantime, for lack of drinking water-supply pipes in many rural areas of the MD, farmers normally take water from the water network during high tide for domestic usage. Actually, less than 50% of the MD's rural population has access to a clean drinking water source and in average only 20% of the MD's households have sanitary latrines [MONRE *et al*. 2003]. Such a practice adversely affects the sanitary conditions in the region, threatening the local people's health.

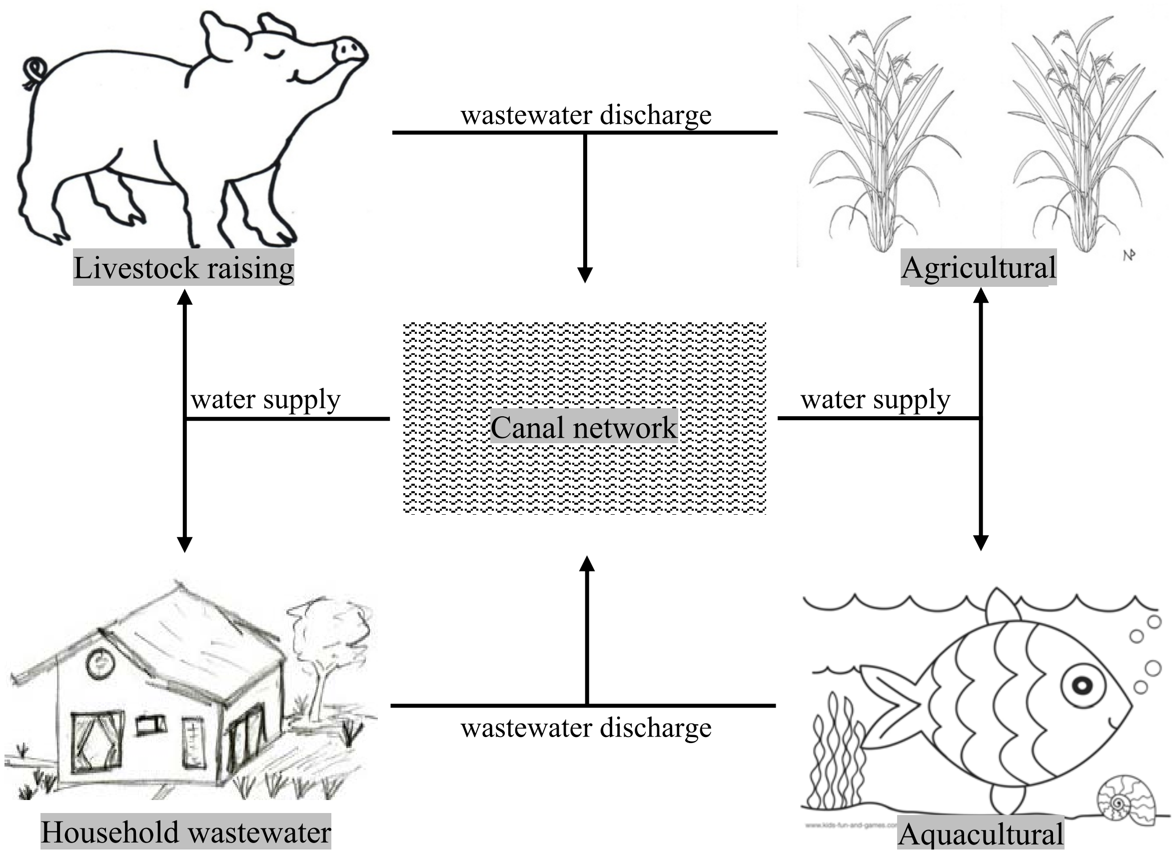


Fig 1.3 Poor sanitary water cycle in rural areas in the MD

1.1.2 Integrated farming systems in the Mekong Delta

Integrated farming is a traditional approach to family farming in rural Vietnam. The elements of this system could be VA (V - garden, and A - fishpond), VC (V - garden, and C - animal husbandry), AC (A - fishpond, and C - animal husbandry), or VAC (V - garden, A - fishpond, and C - animal husbandry). As the output or waste from one element of the system can be applied as an input to the other elements, farmers will choose the integrated farming system appropriate to their own situation. As such, these systems help reduce farmers' dependence on outside inputs, while recycling nutrients to generate a variety of income and nutrient sources [Le, 2001].

Since the 1960s, the VAC farming system has been promoted nationwide in an attempt to deal with malnutrition and poverty after the war [Zhu, 2006]. The application of the VAC model has helped improve living standard of the rural farmers significantly. Nguyen (2008) reported that in some communes of the Red River Delta, farmers' annual income generated from the VAC farming is 3 ÷ 5 times higher (and sometimes as much as ten times higher) than that derived from growing two rice crops per year in the same area. Nonetheless, the system causes some inconvenience; in particular the raw wastes are disposed of directly into fishponds or gardens and then discharged into open water sources, which causes pollution to the main water supplies of the local communities. This is a potential threat to both the sanitary condition and local community health in the rural areas, especially where the local people cannot access a clean water network.

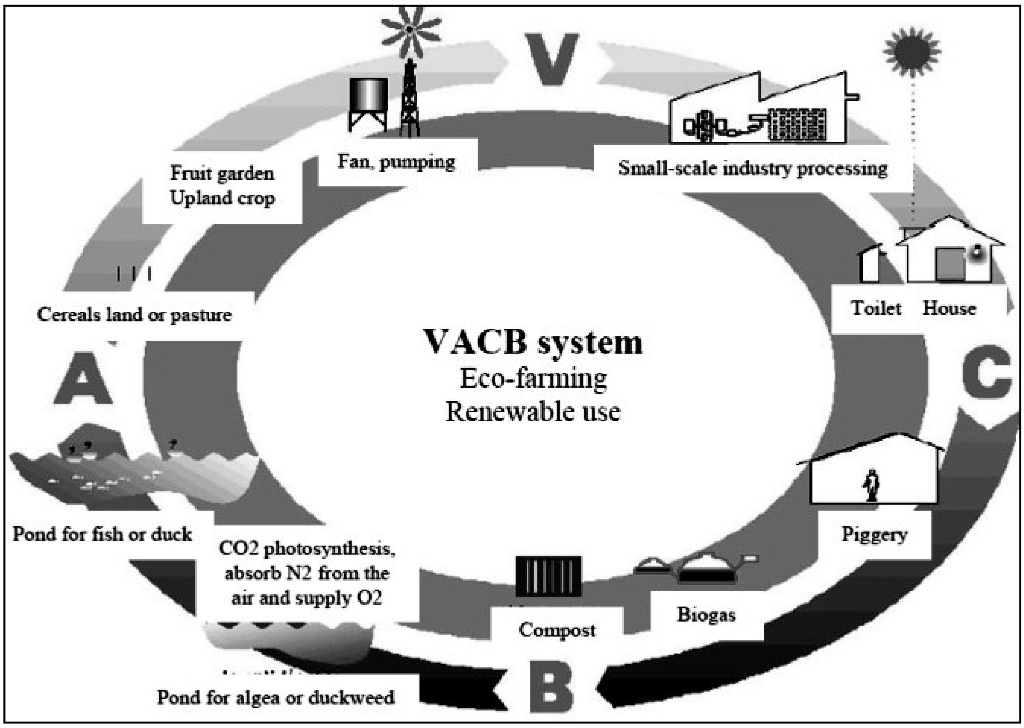


Fig 1.4 The VACB integrated farming system

(Source: REC and CET, 1996)

After introduced and promoted as an appropriate solution for unsanitary conditions in the MD in the 1990s, biogas plants have been added to the VAC model, forming a new integrated farming system, called VACB. In this VACB model, the biogas plant enhances the VAC model as a treatment module not only for animal waste but also for human excreta. Feces are collected in the biogas plant, the slurry accumulates in the plant and due to the input amount it is emptied. The sludge can be dried or composted and used as organic fertilizer. In some cases, the pathogen-free effluent from the biogas plant can be directed into fishponds to make use of the nutrients of the effluent for aquaculture. The produced biogas can be used for cooking, lighting and even for electricity generation.

1.1.3 Research objectives

The MD possesses some typical conditions potential to application of biogas plants. In addition, local farmers have recently acknowledged the benefits of biogas plants. However, the number of biogas plants is still limited in the MD.

There were a few surveys examining the biogas application in the MD, but these surveys seldom provided a profound and comprehensive picture of biogas development in the area. In 2004 there was a survey on biogas user households and non-biogas user households conducted in Can Tho city and Hau Giang province within the SANSED project. The project SNV conducted two surveys on biogas users in two provinces of the MD, one in Tien Giang (in 2005) and the other in Tra Vinh (in 2009). The two projects' surveys focused only on biogas user households to seek for an understanding of biogas application in the survey sites. Meanwhile, to promote a widespread application of biogas plants in the region, it is necessary to do comprehensive surveys on the biogas application concerning all of the core issues related to biogas development such as installment, operation and maintenance of biogas plants at households, and the actual demand on biogas construction in the area. It is also worthy of consideration to do a study on the experience of biogas masons so as to suggest solutions to develop construction works or biogas models suitable to the real local circumstances. This survey, therefore, aimed at assessing the actual status of biogas application as well as the possibilities to install new biogas plants in the MD. The survey is expected to provide detailed and comprehensive practical information in respect of the construction, operation and maintenance of biogas plants and the socio-economic impacts and environmental aspects of biogas application in the MD.

In detail, the survey objectives are as follows:

- The first specific objective focused on biogas household users. It was expected to collect general information related to the households, the construction of their biogas plants, the operation and maintenance (O&M) works of the installed biogas plants, any problems concerning biogas operation, gas usage, by-products application, socio-economic impacts, sanitary conditions, etc.
- The second specific objective was to understand the perception as well as expectation of households without biogas plants on application of biogas plants. The general information on the households, the management of their livestock manure, the socio-economic impacts, sanitary conditions, etc. was collected.
- The third specific objective was to survey the products and services offered by the masons who have built biogas plants. The survey was expected to find out how the masons had offered a biogas building contract to their clients, to get their recommendations of improvement of the biogas plant models, and their opinions on the scenarios of the biogas market in Vietnam for the coming years, etc.

1.2 ANAEROBIC CO-DIGESTION IN THE MEKONG DELTA

1.2.1 Background

Up to date, biogas plant is strongly confirmed not only as a safe treatment for livestock waste but also gas supply for household cooking, lighting, etc. The output from biogas plant can be used to feed fish in a VACB farming system. In spite of the above mentioned benefits of biogas plant, few farmers in the MD can enjoy the full benefits of biogas plants for a long period. In the MD, farmers normally raise pigs at small-scale (from 4 to 10 pig herds per household). Furthermore, in case the market price of pigs is low or the cost of livestock fodder is high, or pig diseases happen, they usually tend to decrease the number of pig herds or even to discontinue raising pigs until the favorable conditions are available. In that case, their biogas digesters just process discontinuously due to lack of pig manure (PM). The instability of PM supply seems to make the investment in installation of biogas digesters wasted. This is one of primary limits to the promotion of widespread application of biogas digesters in the MD, weakening the potentials of favorable conditions of the MD for biogas application and having an impact on environmental pollution prevention in the area. To encourage the use of biogas digesters in the MD, this research aimed to find out additional local input materials potentially relevant to biogas digesters, particularly in case of PM in short supply.

Looking into the real conditions in the MD, among the possible uses, water hyacinth (*Eichhornia crassipes*) is a promising supplemental input to produce biogas [Shiralipour and Smith, 1984; Dirar and El-Amin, 1988; Taheruzzaman and Kushari, 1989]. In case of co-digestion water hyacinth (WH) and animal dung, Eltawil and Belal (2009) tested the anaerobic batch co-digestion of WH and cattle dung (CD) with total solid concentration of treatments from 7.9% to 10%. The results showed that the average gas production rate of the treatment 40%WH+60%CD was 121% compared to the treatment 100%CD. A two-stage rumen-derived anaerobic digestion was tested for the conversion of WH shoots and a mixture of the shoots with CD into biogas [Kivaisi and Mtila, 1998]. This study achieved a 10% increase in the digestibility of WH+CD mixture over that of WH alone under standard rumen conditions. By Mallik *et al*. (1990), the potentialities of WH plus CD and poultry litter (PL), as feedstock for biogas production was determined. Based on total solid value, the total gas production of the treatment 59%CD+17%PL+24%WH attained 78% compared to the treatment 100%CD. In case study in the Sudan, Philipp *et al*. (1983) surveyed gas production from both batch and continuous fermentation with rumen liquor and different preparation types of WH as input materials. For the case of the MD, there is little literature on production of biogas from WH available. The earliest study was conducted by Nguyen and Phan (1989) on co-digestion of PM and WH but the mixing ratios were based on dried weights of input materials. Another research implemented by the Center of Environmental Engineering and Renewable Energy (CEERE) - College of

Technology - Cantho University on processing and technology alternatives for utilization of energetic content of WH [Panning, 2003] showed that WH could be an option for energy production in the MD. Later within the SANSED project, Truong *et al.* (2009) investigated the biogas production of WH at different levels replacing PM as the main substrate by *in vitro* experiments of syringe as compared to the flasks. The authors found that the biogas production was enhanced by increasing replacement levels of WH to PM from 10% to 50% and reached the highest value at 50% levels. Nguyen *et al*. (2011) did a study on gas production from co-digestion of PM and WH with different WH pre-treatment forms. The highest gas produced was recorded from the treatment of PM mixing to whole WH and liquid after hydrolysis WH in 2 days.

In addition to the use of WH, some researchers suggested rice straw (RS) as a potential input additional to animal manure in biogas plants [Mallik *et al*. 1990; Zhang and Zhang, 1999]. However, the high lignin content from RS is a main obstacle to produce biogas. The anaerobic process of RS requires pre-treatment to fully realize potential yield, but in most cases the pre-treatment makes methane production uneconomical in comparison to the current energy prices [Lissens *et al*. 2004; Mishima *et al*. 2006, Petersson *et al*. 2007; Yang *et al.* 2011]. Besides, when using fresh RS, the pesticides remaining inside the straw body could affect the anaerobic microorganism system. Meanwhile, the pre-treatment of RS and pesticide effect could not be a matter if spent mushroom compost (SMC) is used as an additional input material for anaerobic digester instead. As SMC is the residue from rice straw mushroom cultivation, the RS has already been partly degradable, helping shorten the duration of anaerobic process. To the best of our knowledge, there have been a few researches on biogas production from spent straw from mushroom cultivation in the world. Mehta *et al*. (1990) conducted the experiments related to biogas production using SMC. The authors reported that the biogas production from the SMC mixed with CD produced more biogas compared to the one without the mixture of CD. An earlier study by Bisaria *et al*. (1983) recorded an increase in gas yield but by using spent wheat straw from *Pleurotus florida* mushroom planting. The research related to the anaerobic co-digestion of PM and RS in the MD employed only fresh RS. Truong *et al.* (2009) reported that RS could be used as substrate sources to replace PM for biogas production. There has been no research on biogas production from SMC undertaken in the MD.

Both WH and SMC are common in the MD. Coincidently, WH is enormously popular on a dense system of canals in the MD. It rapidly and thoroughly covers the entire surface of waterway - dramatically causing obstacles for water flow, blocking sunlight to native submerged plants, and starving the water of oxygen and often killing wildlife such as fish. In some areas of the MD, local people have to apply herbicide to control WH development, which will possibly pollute the water sources. In parallel, SMC is a popular residue due to a rapid growth of mushroom cultivation at household scale in the MD. In fact, Vietnam has recently become the world's third largest exporter of mushroom with over one million tons of fresh mushroom produce in 2010 [iLumtics, 2008]. Every ton of mushrooms results in one to two tons of dry spent residual material [Rinker, 2002]. It is also worth noting that there is very limited application of SMC for other uses, only small proportion of the SMC is used to cover soil to maintain the soil humidity for vegetable planting in the area. SMC itself as a waste could be a potential threat to the local environment. WH and SMC were therefore chosen in the study due to their potential to biogas plants and high availability with the expectation to promote the widespread development of biogas plants and to recommend a possible solution to the problem of WH and SMC in the rural MD.

1.2.2 Research objectives

The objectives of the study are to test the hypothesis in the context of the MD and to explore the optimal mixing ratios of co-digestion WH+PM and SMC+PM in biogas plants appropriate to the local conditions in MD. The result of this study is expected to contribute locality-based evidence supporting the encouragement of the local owners of biogas digesters to take into account the usage of WH and SMC as potentially additional input materials for their biogas digesters, especially when the animal manure is in short supply.

The experiments were expected to give answers to the questions of:

- The influence of differential mixing ratios of WH or SMC with PM on gas production by batch digester.
- The stability of the semi-continuous anaerobic co-digestion of WH and SMC to PM.

1.3 BIO-SLURRY APPLICATION TO AGRICULTURAL PRODUCTION

1.3.1 The demand for fertilizer in agricultural production in Vietnam

After the reunification in 1975, Vietnamese Government has strongly encouraged farmers to invest in agricultural production, especially food production, to meet domestic demand and for exportation. Vietnam was no longer a net staple food importer but can produce enough staple food for domestic consumption as well as becomes the second biggest rice exporter in the world. As a result, the fertilizer consumption has risen sharply in recent years since high agricultural commodity prices and strong supporting governmental policies to agriculture give farmers more incentives to gain greater profit by more production and higher yield [Bo, 2010]. In average, Vietnam needs from 7.5 to 8.5 million tons of fertilizers per year for its agricultural production.

Although the demand for fertilizers is high, the supply of fertilizers has heavily depended on importation. Fertilizers are mainly imported from China, Russia, Korea, Philippine, etc. Because of being highly dependent upon foreign suppliers, Vietnam's fertilizer market has fluctuated widely over the past years. The prices of fertilizers have doubled, and even tripled sometime, affecting farmer's yearly profits considerably.

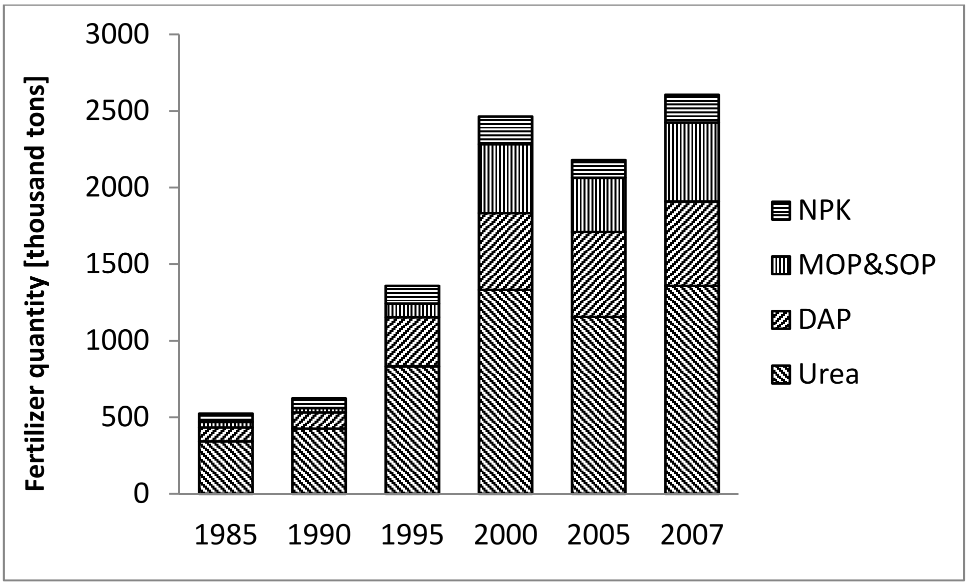


Fig 1.5 The quantity of inorganic fertilizers applied in Vietnam

NPK - Mixtures of nitrogen, phosphorus and potassium; MOP - Potassium chloride; SOP - Potassium sulfate; DAP - Ammonium dehydrate phosphate

(Source: Derived from Truong, 2009)

As shown in Figure 1.6, the application of inorganic fertilizers has tended to increase over years (except for the year of 2005) and made up a considerable proportion of the total amount of fertilizers used for agriculture. Importantly, using inorganic fertilizers for agriculture production may cause negative effects on environment, especially if inorganic fertilizers are overused. Overuse of inorganic fertilizer makes the roots of plants dry out, damaged or even dead due to the effect of "fertilizer burn". More seriously, in case applied to crops, inorganic fertilizer is easily washed away by water or seeps into underground water and exists under the form of un-decomposed matter. Therefore, an increased application of organic fertilizer can help farmers reduce their dependence on inorganic fertilizer and use their land more sustainably.

1.3.2 Utilization of bio-slurry

Laboratory studies and application of bio-slurry for crop have been implemented since the 1940s. Gurung (1997, cited from Desai and Biswas, 1945) showed that bio-slurry had better effect on crops compared to yard manure. In another report by Rosenberg (1952, cited by Gurung, 1997), the experiment results indicated that bio-slurry gave higher yield than ordinary farm yard manure and produced positive effect on crops such as potatoes, vegetables and tomatoes. According to Chawla (1986, cited by Gurung, 1997), during the anaerobic fermentation process about 25% to 30% of the organic matter from the fecal matter was converted into biogas while the rest became available as a residual bio-slurry. This bio-slurry source was considered to be rich in major plant nutrients (NPK) as well as in micro-nutrients such as zinc, iron, manganese and copper, which were generally in short supply in many types of soil [Tripathi, 1993, cited by Gurung, 1997]. Kean and Preston (2001), Ho and Preston (2004) reported that water spinach yield responded linearly to the increasing levels of nitrogen in bio-slurry charged with pig manure.

As regards fishery, Kaur et al. (1987) reported that growth rates of the fish weight were 3.5 times higher in bio-slurry tanks than in the control treatment, while growth rates of common carp in raw cow dung tanks were about 1.2 times higher than in the control treatment. Edwards *et al*. (1988) found that there might be potential for even greater yield from biogas slurry fed into fishponds because the relationship between net fish yield and slurry loading rate was linear. Balasubramanian and Bai (1994) confirmed the biogas effluent could be used as an organic fertilizer to fish culture. Pich and Preston (2001) reported that all of the five fish species (Tilapia, Silver carp, Bighead carp, Silver barb and Mrigal) grew faster in ponds fertilized with biogas effluent than those with manure.

In Vietnam, there are some researches on the application of bio-slurry into agriculture. Nguyen (1989a) known as the first person in Vietnam did research on the use of biogas slurry as fertilizer. He found that the use of biogas slurry as fertilizer resulted in a considerable increase in the crop yield of corn and kohlrabi (26% for corn, and 31% for kohlrabi). The result of the research on the application of solid bio-slurry to potato crops undertaken by the Institute of Energy in 1990 confirmed that the yield of the potato crops applied the bio-slurry increased 64% compared to that of non-applied bio-slurry crops [Le, 2008]. Le (1998a) presented that the biomass yield and the protein content of cassava foliage were significantly increased when bio-slurry, derived from either pig or cow manure, was used to fertilize the cassava in comparison with the same amount of nitrogen applied in the form of the raw manure used to charge the bio-digester. A similar finding was reported for the duckweed grown in ponds fertilized with bio-slurry or raw manure [Le, 1998b]. In 2003, the National Institute for Soil and Fertilizer carried out a research on applying liquid bio-slurry to cabbage cultivation, reporting that such an application helped increase the yield of cabbage planting to 24% [Le, 2008]. Eije (2007) found that farmers saved money on chemical fertilizers and pesticides when applying bio-slurry to their tea crops in the Northern part of Vietnam. Within the project SNV, the bio-slurry taken from the biogas plant fed by 100%PM was applied to fish raising and vegetable planting at household scale [Le, 2008].

In the South of Vietnam, due to the fact that farmers usually use inorganic fertilizers, the studies on bio-slurry utilization are limited. The research carried out by the students from the Renewable Energy Center (REC) of Cantho University on using bio-slurry for soybean planting showed that the application of bio-slurry helped increase the yield more than 20%; the application of the bio-slurry to fish-pond helped increase fish yield up to 10% [Le, 2010]. The primary study by Do *et al*. (1999) recorded that household earned an annual income of about 2,000,000 VND (equivalent to about US$ 100) by application of bio-slurry from TG-BP biogas plants to his/her orchards and fishery. In the SANSED project, Arnold (2009) recommended that the aerobic mixture of bio-slurry and rice straw could produce qualified compost for farming. Similarly, Duong *et al*. (2009) informed that bio-slurry provided the best effects on crop growth and yield on the alluvial soil, specifically with maize cultivation. In this regard, Duong *et al*. (2010a) reported that the application of bio-slurry to maize crops grown on old alluvial soil could increase plant weight 1.64 times compared to the direct application of pig manure. In case of the application of bio-slurry to maize crops grown on acid sulfate soil, the increase is 1.57 times [Pham *et al*. 2010]. Ngo (2010) identified the best formula for green mustard and lettuce crops. In respect of aquaculture, Duong *at el*. (2010b) assessed the effect of supplementation of homemade feed to biogas effluent and pig waste on growth and yield of fish species of Tilapia, Snakeskin gourami, Kissing gouramy and Common carp.

In the connection of co-digestion of PM and WH or PM and SMC, benefits of co-digestion's bio-slurry utilization is poorly understood in the MD. Studies on applicability of bio-slurry from anaerobic co-digestion of PM and WH or PM and SMC to agriculture could optimize the use of anaerobic digesters economically.

1.3.3 Research objectives

The study aimed at testing the possibilities of application of bio-slurry from the co-digestion biogas plants to vegetable planting and fishery. The growth rate of leaf mustard (*Brassica juncea H. F.*) and Tilapia fish (*Oreochromis Niloticus*) would be evaluated when they are applied with different kinds of fertilizers.

1.4 SMALL-SCALE BIOGAS PLANTS IN THE MEKONG DELTA

1.4.1 Background

In the MD some researches on biogas technology have been initiated in the 1960s. However, owing to the massive importation of liquefied gas and inorganic fertilizers during this period, few of the research findings could be applied in reality. After the country's re-unification in 1975, biogas technology again attracted the attention from the central government, which is a lever to put biogas gradually into practice.

There have been some types of biogas plants developed for the MD until now. As reported by Nguyen (1989c), Dr. Hoang Quynh introduced a fixed-dome biogas plant to Can Tho province. After that, REC developed another type of biogas plants known as CT1 model in

1987. This model is an upgraded version of cylinder plant with a fixed ferro-cement gas-holder [Phan, 1989]. Up to 1988, about one hundred CT1 biogas plants have been constructed in Can Tho [Do, 1989].

In 1992, SidaSAREC and FAO funded a study to introduce the polyethylene (PE) digester in the Southern part of Vietnam [Bui *et al.* 1995; Duong and Le, 2002]. At the same time, REC introduced a new model named TG-BP plant made from concrete to farmers in the MD and the TG-BP plant was developed by the scientists of Thailand and Germany within the GTZ project [Le, 2010]. Since then, both of the biogas models have been integrated into the existing VAC farming system in the region, turning this system to a new farming system named VACB.

Since 2003 the Vietnam's Ministry of Agriculture and Rural Development in cooperation with the Netherlands Development Organization has implemented the project SNV. With the commitment aid from Dutch Government, up to 2010, more than 7,000 units most of which are the KT2 model have been installed in the MD.

From 2006 to 2010, Luxembourg Government funded the project Sustainable Production of Aqua-agriculture and Using Renewable Energy from Water Hyacinth and Waste (VIE020) in Hau Giang province. During the project, the scientists of Cantho University have successfully introduced two types of biogas plants named EQ1 and EQ2. The two models have been put into effect and with the project support nearly one hundred units of EQ1 and EQ2 have been constructed within the project area and in other provinces.

The composite biogas plant which originated from China has been introduced to Vietnam by several companies since 2008. The main advantages of the biogas composite are high durability and simple installation. The system has been applied mostly in the northern and central part of Vietnam with more than 10,000 units [EEP, 2010]. In the MD, this model has initially been introduced in recent years but few farmers are interested in this model due to its high investment cost.

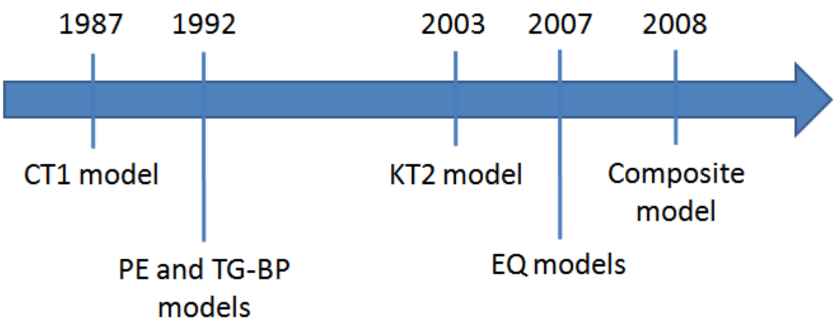


Fig 1.6 The appearing timeline of popular biogas plants in the MD

The existing biogas plants in the MD can be categorized into two types - the fixed-dome biogas plants (TG-BP, KT2, EQ1 and EQ2, composite plant) and bio-digesters (PE digesters). Although the fixed-dome biogas models are long-life time, stable in operation but requires skilled labors and high investment cost. Meanwhile, the PE model is cheaper and easier to install so that roughly 25,000 units have been installed in the Southern part of Vietnam [Duong and Le, 2002]. Additionally, the PE digester is seemingly more popular in the MD than in the other parts of Vietnam because local farmers normally possess larger land holdings in the MD. For instance, the MD's farm households own plots of land ranging from 0.5 to 3 ha while the average cultivated land area for a household in the north is 0.28 ha [Bui and Nguyen, 2001]. However, the PE digester has some shortcomings such as short life time, high vulnerability to outside damaging factors, and low gas pressure qualified for lighting.

1.4.2 Research objectives

In order to promote the application of biogas technology in the MD, it is necessary to develop a digester model fixing the shortcomings of the fixed dome digesters as well as the PE digester. To solve the existing deficiencies concerning the biogas application in the MD, the new model of biogas plants is expected to have such benefits as (i) reasonable cost, (ii) acceptable lifetime, (iii) easy to install, and (iv) sufficient gas pressure for lighting. Furthermore, as most of the land is low in the MD, it is difficult to apply concrete digesters, especially when the water level rises up. Meanwhile, the PE digesters form can be suitable to low-lying areas. It assumed that new digester could be an upgrade version of the PE digester with extension of lifetime and improvement in gas pressure. The study aimed to develop a new digester model made from HDPE which is expected to fix the shortcomings of the existing digester models.

1.5 APPROACH AND ORGANIZATION OF THE STUDY

In an attempt to recommend possible solutions to the promotion of the large-scale application of biogas plants and the development of the VACB farming system applicable to the real situations in the MD, the study concentrates on the following issues:

(1) Doing a survey on the current status of biogas application in the MD to figure out the favourable and challenges to the development of biogas technology, and the local people's demand for biogas plant installation.

(2) Undertaking anaerobic digestion experiments to test for the possibilities of some local residues (particularly WH and SMC) in being used as potential supplements to PM, the primary local input of biogas plants.

(3) Evaluating the quality of bio-slurries derived from the co-digestion processes of PM and WH, and of PM and SMC as organic fertilizers for both the growth of algae, a fish feeding, in fishpond and that of vegetable planting.

(4) Developing a new biogas digester model suitable for the local circumstances and requirements in the MD.

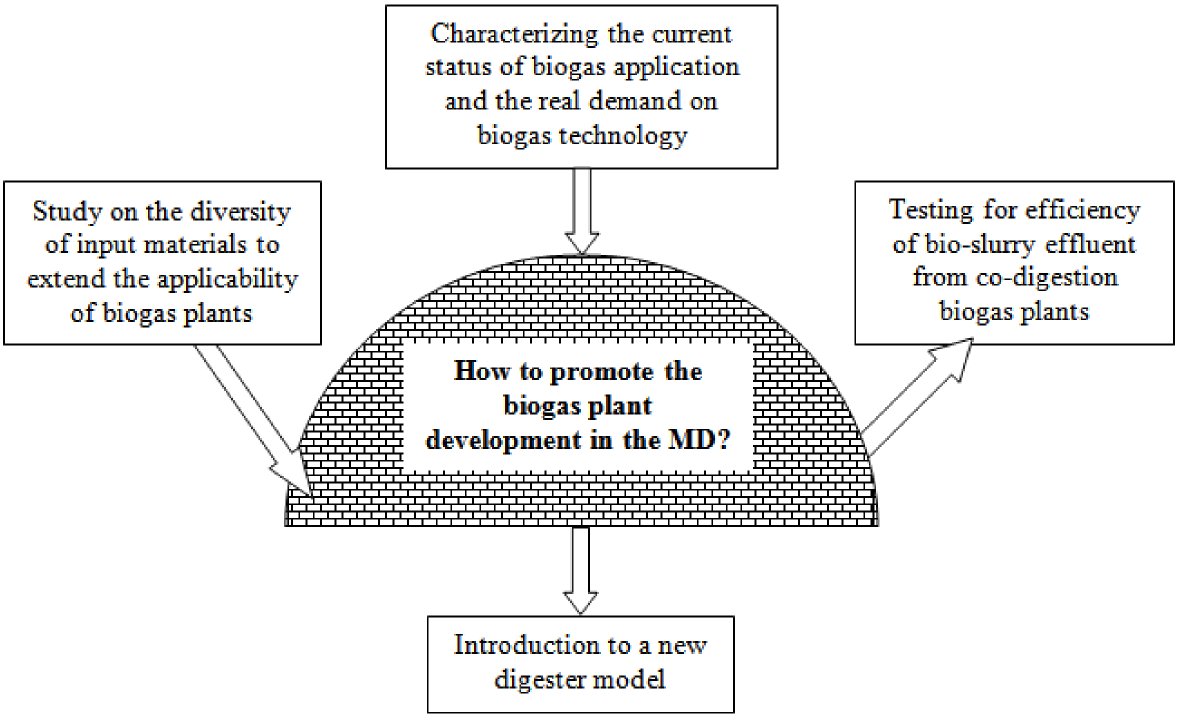


Fig 1.7 The scheme of the investigation

The research is organized into 7 chapters. Following the introductory chapter, Chapter 2 presents the methodology for all works in this study. Chapter 3 refers to the survey results of the three selected sites in which in-depth information on the current application of biogas plants at the local biogas household users as well as the attitude of the local non-biogas households to biogas technology is revealed. Chapter 4 presents and discusses the testing results of the co-digestion of PM and WH and that of PM and SMC in lab scale. The batch experiments were conducted to test the optimal mixing ratios of input materials, while the semi-continuous experiments were conducted to check the loading capacity of feeding materials. The productivities of the Leaf mustard plant and Tilapia fish applied the bio-slurries of the co-digester are analysed in Chapter 5 in which the efficiency of the bio-slurries application was evaluated by a statistic tool. Furthermore, Chapter 6 develops a new digester model for the MD and presents the preliminary findings of its farm household-scaled application. Finally, the conclusions and some outlooks to the biogas development in the MD are concluded in Chapter 7.

CHAPTER 2. METHODOLOGY

2.1 BIOGAS APPLICATION SURVEY METHODOLOGY

2.1.1 Site selection

For understanding of the actual biogas application in the MD, a survey was conducted in some provinces of the MD. In order to make the survey informative and comprehensive, the provinces where the survey would be conducted had to meet some criteria. There must be some biogas support projects available in the selected sites, and there must be a considerably large number of households having installed biogas plants so as to make convenient for the interviews of the biogas users. Furthermore, the interviews of non-biogas users and biogas masons would be processed at the same sites to save time and expenditure. By that way, it would be convenient for making a clear evaluation of the influence of biogas application on the biogas user group as well as non-biogas user group.

By this approach, the three provinces of the MD were selected for the survey, consisting of Can Tho, Hau Giang and Dong Thap:

(1) Can Tho city: the interview conducted at the suburban areas of Long Tuyen ward and Long Hoa ward of Binh Thuy district, and My Khanh ward of Phong Dien district. The three survey areas are typical suburban communities with agricultural production such as fruit trees, rice cultivation, upland crops and aquaculture.

(2) Hau Giang province: the interview focused on the rural communities of Long My district and Phung Hiep district. The two survey communities are very remote, which limits the market exchange opportunities of household products. The household's income there mainly comes from rice cultivation, upland crops and aquaculture.

(3) Dong Thap province: the survey executed at a traditional village where the farmers produce rice powder at Tan Phu Dong ward of Sa Dec town. In this site, the local people apply the by-products from rice powder production to feed pigs. Revenue from rice powder production and pig cultivation are the main income of the local farmers.

These three selected sites provided the following convenience for the survey:

- Having the typical characters of the communities concerning agricultural production and living standard of the MD.
- Being a transect from suburban area to rural area and a traditional village, offering the possibility to obtain various information on the local communities.
- There are available contact-persons who can help communicate with the local farmers for the survey.

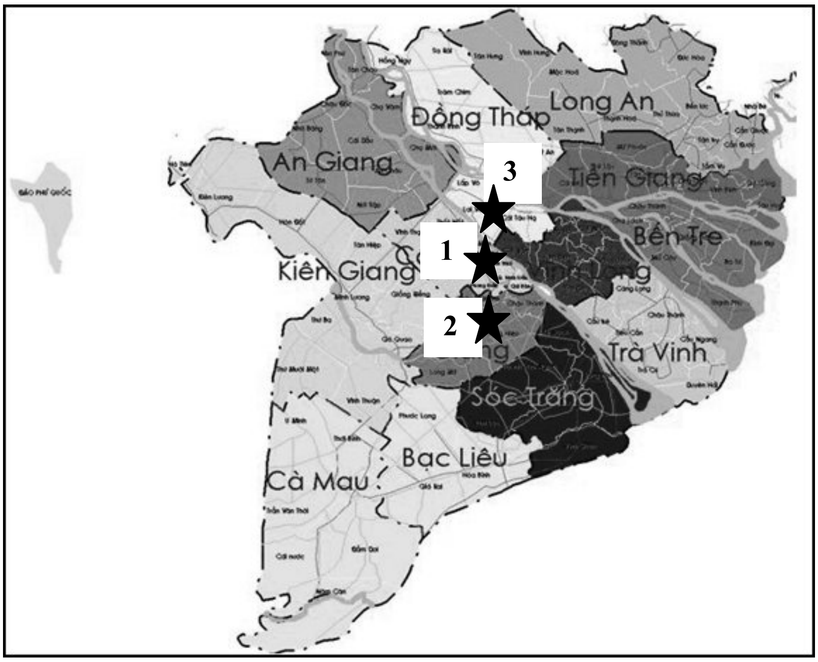


Fig 2.1 The map of the selected sites for the survey

2.1.2 Sample selection

First of all, the information on target groups was collected from the local authorities and former project's staff. However, the information from the People's Committees concerning the households with or without a biogas plant was little reliable in the case of Hau Giang and Dong Thap. The local authorities at these provinces provided us a list of non-biogas user households, but in fact some of these listed households have already installed a biogas plant. Because of the unreliability of the provided information only happening to the case of Hau Giang and Dong Thap, the samples in Hau Giang and Dong Thap were chosen based on a farmer-to-farmer approach while the samples in Can Tho were randomly chosen based on the provided information. The farmer-to-farmer approach means when conducting an interview at one biogas user household, they were requested to recommend any other biogas users they know, and then the recommended households were chosen for the next interview. This method also applied for the sample selection in regard to non-biogas users and biogas masons.

2.1.3 Data collection

There were two approaches processed based on two sources of data:

- The related secondary data were collected from the available relevant previous reports from government authorities and projects.
- The primary data were collected from the survey and interview. There were three interview groups, consisting of (i) biogas user households, (ii) non-biogas user households, and (iii) biogas masons.

2.2 ANAEROBIC CO-DIGESTION METHODOLOGY

2.2.1 Research preparation

There were 36 sets of airtight digestion apparatus installed of which 30 digesters for batch fermentation and 6 digesters for semi-continuous fermentation. Each was composed of a 20 L plastic bottle connected to a gas collection pipe. All bonds from the digester body (the inlet, outlet, and gas pipe) were connected by soft joints for airtight and watertight. To minimize the development of algae population that creates oxygen inside the digesters, all bottles were covered by black nylon bags throughout the testing period. A 15 L aluminum bag connected directly to each of the digesters through its gas collection pipe in order to collect gas samples. There were two air-valves installed to the pipes in connection with the digester and the gas-bag so as to switch the gas off when the gas was being recorded.

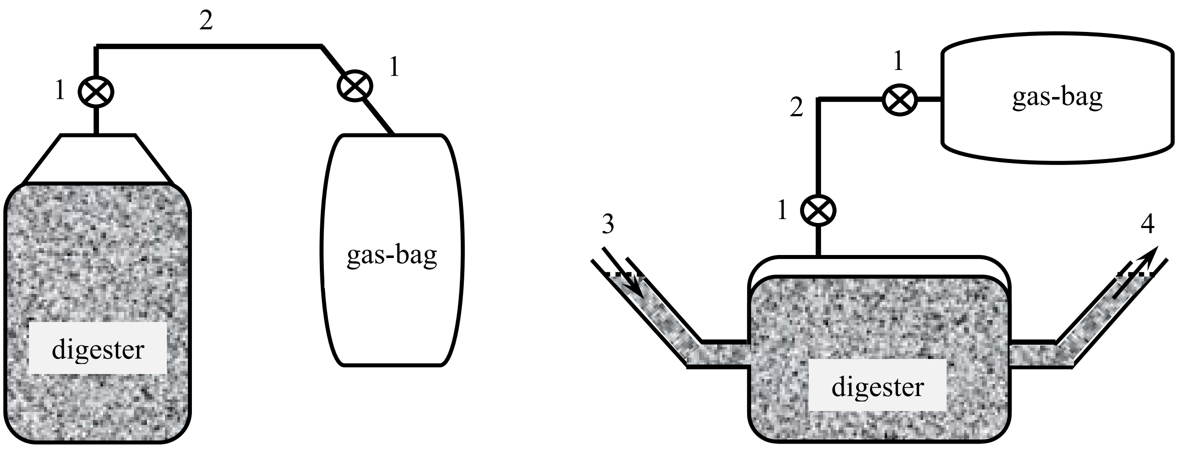


Fig 2.2 Treatments on batch experiments (left) and semi-continuous experiments (right)

(1) the air-valve; (2) the gas pipe; (3) the inlet; (4) the outlet

2.2.2 Material preparation

The input materials loaded for the anaerobic process were prepared as follows:

- Dry PM collected from piggeries at Hoa An Center (located 40 km south of Cantho city) was air-dried out at ambient temperature (about 25 ± 4°C) for one week before coming into use, and then the dried PM was manually mashed and mixed up until it became a homogenous form.
- WH was collected from the waterway around Hoa An Center. The roots of the WH were removed and only its body and leaves were manually cut into approximate 1.0 ÷ 2.0 cm long pieces. Then the WH pieces were air-dried at ambient temperature up to unchanged weight. After completely dry, the dried WH was manually mixed up until it became a homogeneous form.
- SMC was collected from the farmers' households producing straw mushroom around Hoa An Center. The SMC were manually cut into approximate 1.0 ÷ 2.0 cm long

pieces. Like the WH, the chopped SMC was air-dried at ambient temperature up to unchanged weight, and then manually mixed up completely.

- Inoculums: to shorten the time of gas production, the seeding material which is the effluent taken from an existing active biogas plant was used. This is a 100 m^3 biogas plant currently applied to treat the wastewater from the piggeries at Hoa An Center.

2.2.3 Analytical methods

The ratio of PM to WH and SMC in the mixture was defined based on their organic dry matter (ODM) value. Before the experiments were conducted, the ODM values of input materials had been analyzed according to the procedures in the Standard Methods for the Examination of Water and Wastewater which guideline by APHA (1995).

The substrates before and after the experiments were taken and analyzed for pH, carbon (C), total Kjeldahl nitrogen (TKN), dry matter (DM), ODM, alkalinity according to the procedures of APHA (1995).

The gas measurements were taken after two day operation of the batch treatments and after one week operation of the semi-continuous treatments. The gas production was recorded daily with Ritter gas-meter (with the smallest scale of 20 mL), the biogas components were monitored weekly by a GA94 gas analyzer. Before each sequence of analysis, the GA94 was calibrated with CH_4 and CO_2 gas standards.

The gas record was expressed at ambient temperature and at stable atmosphere pressure (1004 ÷ 1006 mbar).

All of the anaerobic digestion experiments and the physical - chemical analysis were conducted at the Environmental Engineering Laboratory of the College of Environment and Natural Resources of Cantho University in Vietnam.

2.2.4 Experimental set-up

a) Batch treatments

For the PM+WH treatments, 14.5 L inoculums was mixed together with 630 g mixture of PM and WH (based on ODM values). According to the study by Nguyen *et al*. (2011), to speed up the gas production, the dried WH had been hydrolyzed by the inoculums for 2 days before all of the WH juice and WH residue were loaded into the digesters. Five co-digestion batches of PM and WH were set to evaluate the influence of various mixing ratios on gas production. Each of the treatments was in triplicate.

- WH0: 100%PM + 0%WH
- WH1: 75%PM + 25%WH
- WH2: 50%PM + 50%WH

- WH3: 25%PM + 75%WH
- WH4: 0%PM + 100%WH

As regards the experiment on SMC, the treatments of PM+SMC were processed with the same procedure as applied to the batch treatments of PM+WH, but the SMC was directly loaded into the digesters without pre-treatment. There were 665 g of PM+SMC (based on ODM values) mixture in 17.5 L inoculums. Each of the treatments was set in triplicate.

- SMC0: 100%PM + 0%SMC
- SMC1: 75%PM + 25%SMC
- SMC2: 50%PM + 50%SMC
- SMC3: 25%PM + 75%SMC
- SMC4: 0%PM + 100%SMC

All of the batch treatments were allowed to be fermented for 28 days and were mixed up by shaking the digesters manually once a day so as to increase the gas production. In the MD, the normal retention time of the biogas plant is 20 days. So that the 28 testing days was chosen for this study to check for the fermentation status of biomass, and to not extend much the volume of digester in case further apply onsite.

b) Semi-continuous treatments

A semi-continuous treatment of 75%PM+25%WH and that of 75%PM+25%SMC were set up in triplicate. The digesters were fed daily at the same time-point. In these treatments, only the action of feeding the digesters helped stir the substrate inside the digesters. The semi-continuous treatments were conducted for a 90 consecutive day period.

- R1 (75%PM+25%WH): 14.5 L inoculums and 22.5 g ODM mixture of PM and WH were added as starting materials in which the dried WH was hydrolyzed for 2 days. From the 2^{nd} day, 725 mL inoculums and 16.88 g ODM of PM plus 5.63 g ODM of WH were added daily.
- R2 (75%PM+25%SMC): 17.5 L inoculums and 23.75 g ODM mixture of PM and SMC were added as starting materials. From the 2^{nd} day, the daily feeding rate included 875 mL inoculums and 17.81 g ODM of PM plus 5.94 g ODM of SMC.

2.3 BIO-SLURRY APPLICATION METHODOLOGY

2.3.1 Research location

The experiments on fish raising were conducted at farming households in Hoa An commune while the experiments on vegetable planting were conducted at the Experiment site of the College of Environment and Natural Resources, Cantho University. In Hoa An commune, some farmers built an EQ2 biogas plant with a crank-handle in order to make the co-digestion of PM and biomass possible. The farmers chosen for the experiments had been requested to feed their existing biogas plants with the PM+WH and PM+SMC before the bio-slurries from their biogas plants were collected and applied to the experiments.

After some trials, the mixing ratios of co-digestion of 90%PM+10%WH and that of 90%PM+10%SMC (based on ODM values of input materials) were finally selected. The physical - chemical analysis was processed according to APHA (1995) and taken at the Environmental Engineering Laboratory of the College of Environment and Natural Resources, Cantho University, Vietnam.

2.3.2 Experiments set-up for leaf mustard testing

a) Design and measurements

Leaf mustard was grown from the seeds in lab-scale pots of 30 cm × 30 cm × 25 cm (length × width × height) which were laid out in a randomized block design. The soil was prepared in homogenous form and then 10 kg of the soil was put into each of the pots.

The leaf mustard was planted at 2 ÷ 3 cm depth on June 10th 2011 and the space between the seeds was 15 cm. Each pot contained four units of leaf mustard. The leaf mustard will be ready for harvest after planted for 40 to 45 days. The growing rate of the leaf mustard was measured four times during its growing period. The measurements were made on the 15th, 26th, 33rd and 43rd day of the growing time. Each treatment contained 12 replicates, so that three of the pots were used for one measurement.

Each of the measurements followed the following procedures:

- The plants in three of the 12 pots were used for one measurement. All of 12 plants were pulled out, weighed and measured for plant height in average (without their roots). Then, the biggest leaf was selected and measured for leaf height and leaf width.
- Right after the measurement was done, all of these 12 plants (excluding their roots) were used for the analysis of ODM and Salmonella. The analysis methods were based on APHA (1995).
- Soil samples were taken before and after the harvest for the analysis of humidity and primary nutrients of nitrogen (N), phosphorus (P) and potassium (K).

Statistical analysis: the data were analyzed by Duncan's Multiple Range Test using SPSS software version 13.0.

b) Fertilization

The planting work based on the guidelines on the amount and timing of fertilization applicable for leaf mustard crop as suggested by Tran (2010). Accordingly, a leaf mustard crop should be fertilized on the 0, 10th, 15th, 20th and 25th day of the growing period. The inorganic fertilizer (IF) treatment followed the amount and timing of fertilization in the guideline. Meanwhile, in regard to the other treatments related to the bio-slurries, first the nutrients containing in the bio-slurries were determined in order to help make up a volume of bio-slurries equivalent to the required amount of fertilizer as suggested by the guideline. Then, the volumes of the bio-slurries equivalent to the required amount of fertilizer were daily applied to the treatments. The bio-slurries were directly watered into the foot of the plants that limit the spreading of the bacterium from the bio-slurry onto the plants.

Eight treatments were set up based on the seven kinds of the fertilizers applied for the leaf mustard. They included PM0, PM1, SMC0, SMC1, WH0, WH1, IF (applied inorganic fertilizers), and C0 (the control treatment with water applied only).

Table 2.1 The leaf mustard treatment design

Treatment	**Applied bio-slurry**			**Applied bio-slurry plus P and K**			**Others**		
100%PM	PM0	PM0	PM0	PM1	PM1	PM1			
90%PM+10%SMC	SMC0	SMC0	SMC0	SMC1	SMC1	SMC1			
90%PM+10%WH	WH0	WH0	WH0	WH1	WH1	WH1			
IF							IF	IF	IF
C0							C0	C0	C0

2.3.3 Experiment set-up for Tilapia fish testing

a) Design and measurements

In this study, Tilapia fish was chosen for testing due to the fact that it can tolerate poor water quality and there is a large market opportunity with a stable price for this fish. The fish was raised in the 1 m × 1 m × 1 m nets with triplicate for each treatment. The fish density was 10 units per net. The fish under the experiments started to be raised at the age of 6 weeks with the fish average weight of 5 ÷ 7 g. To limit the exchanged water from the inside and outside of the experiments, the nets were enclosed by a transparent PVC layer.

The experimental fish were released into the nets on June 27th 2011. The fish was given one week to get used to their living environment. After that, every ten days, three of the fish from each net were randomly picked up. The weight, length and width of the picked fish were measured by the scale (with maximum of 500 g weight) and the ruler. After the measurement, the fish were released back to the experiment nets.

Statistical analysis: the data were analyzed by Duncan's Multiple Range Test using the SPSS software.

b) *Feeding*

Based on the kinds of food supplied into the experiment nets, the fish were divided into four groups of fish raising treatments - no food supply, solely bio-slurry from biogas plants, bio-slurry + commercial food (CF), and solely CF.

Table 2.2 The Tilapia fish treatment design

Treatment	100%PM			90%PM+10%SMC			90%PM+10%WH		
No food supply	PM0	PM0	PM0	SMC0	SMC0	SMC0	WH0	WH0	WH0
Solely bio-slurry	PM1	PM1	PM1	SMC1	SMC1	SMC1	WH1	WH1	WH1
Bio-slurry + CF	PM2	PM2	PM2	SMC2	SMC2	SMC2	WH2	WH2	WH2
Solely CF	PM3	PM3	PM3	SMC3	SMC3	SMC3	WH3	WH3	WH3

The CF was fed into the fishponds two times a day. As suggested by [Pham, 2009], the amount of the CF for one time of feeding is estimated based on the weight of the fish. Accordingly, the amount of the CF should be equivalent to 4 ÷ 6% of the fish weight. Based on such a suggestion, we fed the fish with the amount of CF equivalent to 6% of the fish weight for the first month and 4% for the later months. Like the CF, the bio-slurries was supplied into the experiment nets two times a day with the feeding volume, as suggested by [Veenstra and Polprasert, xxx], of 150 kg COD.ha^{-1}.day^{-1}. During the testing period the COD values of the bio-slurries were analyzed three times in order to determine the volumes of bio-slurries to be required for each treatment.

2.4 SMALL-SCALE ANAEROBIC DIGESTERS IN THE MEKONG DELTA

2.4.1 Material

In recent years, high-density polyethylene (HDPE) material is available in local markets with acceptable price. Compared to PE digester, the HDPE lining is an ideal choice for the most demanding applications in several ways.

- Low permeability: HDPE lining systems are secure because leachate does not penetrate them, and methane gas will not escape from the HDPE cover system.
- Chemical resistance: HDPE - resistant to a wide range of chemicals - is not threatened by typical solid or hazardous waste leachates. It is also suitable for sludge and secondary containment around chemical storage facilities.
- Ultraviolet resistance: HDPE's resistance to UV exposure is further enhanced by the addition of carbon black. Additionally, with the absence of plasticizers, volatilization is not a matter.

- Reflective factor: there is black in HDPE layer. The black surface helps extend liner temperature extremes that are good for fermentation process.
- Easy to fix: HDPE lining is easily fixed by simple technique if there is a hole on it.

Because of its aforementioned advantages, HDPE lining was chosen as material for the new digester. The design of the new HDPE digester basically stems from the PE digester model, but there are some modifications in order to help simplify the installation work.

2.4.2 Methodology

The digester installation: the HDPE digester was installed onsite at O Mon district of Can Tho city where farmers raise breeding pigs. The design of the new digester was generally based on the technical guideline of installation of a PE digester made by Aguilar (2001), and Rodriguez and Preston (xxx).

Treatment efficiency testing: the influent and effluent samples were taken from the new digester on the 30th and the 60th day of its operation. The testing parameters included pH, alkalinity, total solid (TS), volatile suspended solids (VSS), BOD_5, total Kjeldahl nitrogen (TKN), and total Coliform. The analysis works followed the guidelines in APHA (1995).

The biogas quality testing: after the HDPE digester had been installed and operated for a month, the produced biogas was collected and defined the CH_4, CO_2 and O_2 containing in the biogas every week within a month. The Geotechnical GA94 gas analyzer was used for this purpose.

CHAPTER 3. BIOGAS APPLICATION AND ITS POTENTIAL PROMOTION IN THE MEKONG DELTA

3.1 SURVEY PROCESSING

3.1.1 Pre-survey

In this step, many biogas-related documents were collected and reviewed to have an in-depth understanding on the biogas application situation. These secondary data sources supplied generic knowledge on the current application of biogas plants in Vietnam as well as in the MD that was very useful for the survey works.

Moreover, farm households who own or do not own a biogas plant were visited for explorative interviews and inspections. These activities offer an insight overview on the application of the biogas plants at the household scale and the living conditions of the farmers in the MD. Together with the information supplied from the secondary data sources as mentioned above, the interview questionnaires were developed and the design survey was planned as well.

3.1.2 Pre-interview

Based on the information acquired from the pre-survey, three questionnaire sheets were designed - one for biogas users; one for non-biogas users and the last for biogas masons. The interviewer group included two undergraduate students with background on environmental engineering. These students also got involved in the pre-survey so that they could understand the questionnaire and its contents thoroughly.

For the questionnaire sheets, it was designed in form of optional questions and open questions and then applied personal interview. By face-to-face interview, it was easy to ask farmers about the information which the interviewers could not get from the local authorities. Besides that, by undertaking the interview at the farm households, the interviewers could observe and record the real situations on biogas application not only by recording the words but also by taking pictures.

First, the pre-interview on biogas user and non-biogas user groups were carried out at An Binh, a suburban area near Can Tho city. Five biogas users, three non-biogas users, and one biogas mason were interviewed. Other survey sites in Hau Giang and Dong Thap were not involved in the pre-interview because of their distant location from Can Tho. The information collected from the pre-interview helped adjust the questionnaires in order to get highly valuable relevant information from the target groups for the research.

3.1.3 Fieldwork

The interview in Can Tho and Hau Giang was processed in September 2010 while the interview in Dong Thap was conducted in October 2010. For the convenience for the interview works, first the local authorities were contacted to ask for the interview permission. According to the length of each questionnaire sheet, there were five to six interviews processed per day. The interview duration was about 30 minutes for one biogas user, 20 minutes for one non-biogas user, and 10 minutes for one biogas mason. In Vietnam, a household head is usually male, but in this survey, the interviewees are males, females or even couples. All interviewees were friendly and hospitable, particularly the biogas user interviewees always offered hot tea cooked by the produced biogas. Small gifts were prepared to give the interviewees as a thank-you gift for their time and patience.

There were 110 households selected and interviewed, including 77 biogas user households and 33 non-biogas user households over the three provinces of Can Tho, Hau Giang and Dong Thap. Nevertheless, 9 biogas masons who live in Can Tho and Hau Giang were interviewed. The interviewed households at each study site are shown in the table below.

Table 3.1 The number of interview groups

Interview groups	**Location**			**Total in group**
	Can Tho	***Hau Giang***	***Dong Thap***	
Biogas users (household)	24	24	29	**77**
Non-biogas users (household)	13	14	6	**33**
Biogas masons (household)	4	5	-	**9**
	Total			**119**

3.2 BIOGAS SUPPORT PROJECTS IN THE SURVEY SITES

3.2.1 Can Tho city

Can Tho city is a centrally governed city in the MD. Can Tho has an area of 1389.59 km² and the population of 1,187,089 people [GSO, 2010]. With an area of 114,400 hectares of agricultural land used for growing rice, vegetables and fruit trees in which the main crop is rice. Annual rice production is 1.1 to 1.2 million tons of rice, of which about 500,000 to 600,000 tons of special rice for export. Fruits are very diverse and rich to produce of 113,000 tons. Livestock are mostly pigs and poultry and aquatic products output reaches about 198,000 tons [GSO, 2010].

In respect of livestock husbandry, the farmers in Can Tho mainly raise pigs and poultry. The farmers also raise some other kinds of livestock such as cattle, dairy cow, etc. but they are negligible quantity. In recent years, livestock disease situation has become more complex, especially the blue-ear pig disease which has affected pig quantity not only in Can Tho city but also for the whole MD. Even in some places, the farmers have to stop raising pigs and move to other occupations.

Some biogas support projects have been undertaken in Long Tuyen, Long Hoa and My Khanh wards. The Oxfam program (managed by Cantho University's staff) was designed to alleviate poverty with community-based conservation, introducing VACB model in these areas. Another support came from Heifer International in conjunction with giving cows or pigs to the beneficiary; and Heifer introduced biogas technology to poor farmers. In recent years, the project SNV has supported the local farmers to build biogas plants in the areas.

3.2.2 Hau Giang province

Hau Giang province is located in the center of the West sub-region of Hau River with an area of 1601.1 km² and the population of 758,000 people [GSO, 2010]. In Hau Giang, agriculture, forestry and fishery are identified as leading economic sectors that get priority investment in the early stages of the process of industrialization - modernization of the province. The growth rate reached 11.8% in the period of 2004 ÷ 2008 and increased steadily in all of the three sectors.

Located in a less flooded area in the MD, Hau Giang province has advantages in livestock development. Pig raising is concentrated mainly in the Long My, Phung Hiep and Vi Thuy districts. The number of pigs in the province in 2005 was 175,000 and increased to 249,800 in 2006. However, due to the disease situation, the number of pig in 2009 reduced to 151,400 heads. In recent years, the quantity of pigs has increased. The pig development direction is to find and expand pig markets, promoting the pig farm model, particularly focusing on applying new breeders, improving the breeding technique, reducing the food to lower investment cost, and improving quality.

The survey areas are located about 50 km in south-west direction from Can Tho city. Long My and Phung Hiep districts were chosen for the survey because the project VIE020 has been implemented there. This project was financially supported by Luxembourg Government from June 2006 to March 2010. Within this project, the scientists from Cantho University have designed and introduced two biogas plant models of EQ1 and EQ2. The project has already supported and constructed more than 70 biogas plants in the survey areas.

3.2.3 Dong Thap province

Dong Thap province has the population of 1,667,700 people in an area of 3375.4 km² [GSO, 2010]. Located at the upper side in the MD, Dong Thap has strengths in agriculture and aquaculture with annual average food production of 2.6 million tons for consumption and export. It is also the location for many famous fruit trees such as longan, pomelo, mango, pink-mandarin, etc. Especially the flower and decorative plant region in Sa Dec town with over 298 hectares and hundreds of ornamental flowers provide flowers and plants for the nationwide trade and exportation.

The number of pigs was 317.200 herds in 2005 and went down to 290.600 herds at early 2009 due to pig disease - PRRS. Only at the survey site of Tan Phu Dong ward, Sa Dec town, the total number of pig herd is 11,629 heads in 2010. Tan Phu Dong is a more than hundred-year-old traditional village on rice powder. There were 850 over 1,200 households in this village involved in rice powder production. Everyday each household needs nearly 100 ÷ 140 kg of rice and the output is 70 ÷ 100 kg rice powder, 30 ÷ 40 kg lees and 2 ÷ 3 m^3 of wastewater. The by-product (lees) from the rice processing is used as food for pig raising at most of rice powder production households with about 40 ÷ 60 pig herds per household. Despite raising pigs in large number, all the waste from the pigsty discharged directly to open canals without any treatment. But then the water from this canal network was used as a water supply source for the whole activities in this area.

The CEERE implemented a project to promote the commercialization of TG-BP biogas plants (TPD) to improve the poor sanitary conditions at this village. With the fund supported from the Bread for the World (BfdW), this project focused on (i) improvement in community's sanitation and rural people's health, (ii) effectively spreading biogas technology and developing a commercial viable biogas sector in the project area, and (iii) contributing to rural development and environmental protection via provision of clean and affordable energy to rural households. From February 1999 to August 2003, the project provided credit for farmers to build 21 TG-BP biogas plants in total volume of 198 m^3 and supported credit for the quality control of 40 TG-BP biogas plants in total 316 m^3. Aacknowledging great benefits of biogas technology on waste treatment, over 250 households constructed biogas plants at their own expense. Besides that, Australian Government also funded 200 million VND to install more biogas plants as an attempt to help prevent the environmental pollution in this area.

3.3 GENERAL INFORMATION ON THE SURVEYED HOUSEHOLDS

3.3.1 Social conditions

The three survey communities can be distinguished according to their location and professional characteristics such as a transaction from a rural to a suburban area and a traditional village. In this sense, the survey sites in Hau Giang have absolute rural characters. Meanwhile the survey sites in Can Tho have some dynamics of suburban characters. For Dong Thap's sites, it is a traditional village and is regarded as a bridge from rural area to suburban area.

For all the survey households, the information concerning the gender of the household' heads was collected. There are 58 and 21 male household heads at 77 biogas user households and 31 non-biogas user households, respectively. The percentage of women playing a key role in the family is higher at the suburban areas than at the rural areas. On the other hand, as men often take charge of hard work and get more income in the rural areas, most of the household heads are males.

Concerning the total 117 surveyed households, divided into the group of biogas users, of non-biogas users and of biogas masons, the family size was 5.1, 4.8, and 4.2, respectively. In average, the family size of 4.7 in this study is lower than the value of 5.2 persons per household recorded by Wieneke (2005) in his survey conducted at An Binh and Long Tuyen - Can Tho, and Hoa An - Hau Giang. Nonetheless, both these values are higher than the average family size of 4.0 persons in the MD that was announced in the Vietnam Census 2010 [CPHCSC, 2010]. The difference could be due to small samples in these surveys but it showed the high workload needed for agricultural sector in general.

For both the group of biogas user households and of non-biogas user households, the average number of members at each household at Dong Thap site is highest while this value is lowest at Hau Giang site. The average population per household in Dong Thap is high due to the labor-consuming production of rice powder and pig raising. Most of the households at Dong Thap site produce rice powder and raise pigs as a hereditary job that maintains the large number of members at the same household. In contrast, at the Hau Giang site, this is a rural area of acid-sulfate soil with fewer opportunities for cultivation so that the local people have a trend to move out of their homeland to find a job in urban areas. In fact, the CPHCSC (2010) reported that there are 4.6% of the people in the MD migrating while the population growth rate is only 1.96% in the MD. The rural-urban migration reduces the number of the household members in the rural areas.

A small family household of 4 to 5 persons needs approximately 1 m^3 of biogas for daily cooking demand. It means if the household raises from 6 to 10 pig herds (approximately average weight of 70 kg for each pig herd), and constructs a biogas plant with the capacity of 4 to 6 m^3, this plant could be able to treat the pig waste well. Additionally, the daily produced biogas from this plant could provide enough energy for household cooking and lighting at normal demand. A household in the MD usually raises 6 to 10 pigs and this is a great potential for widespread biogas plant application in the region.

The education background of members in the biogas user group is higher than that of the non-biogas user group. The average percentage of the biogas user group attending high school and secondary school is 36% and 31% respectively, while these values of the non-biogas user group are 36% and 16%. Furthermore, 2.4% of the people in the non-biogas user group do not attend any school, while only 1% in the biogas user group. In comparison with the report of the CPHCSC (2010) for the over five year-old people, there is 6.6% of the population in the MD not attending any school, 48.5% attending secondary school, and 13.3% attending high school. For the households with a higher level of education, the household members had more opportunities to approach the innovations and they could accept the biogas technology easily and quickly. In contrast, the less educated households need more and frequent dissemination of biogas plant application via direct communications, the simple and clear presentation methods.

Within the biogas user group, the members of the survey households in Can Tho have higher education level than those in Hau Giang and Dong Thap. The educational level of high school and university levels were 26% and 20% in Can Tho, 39% and 7% in Hau Giang, and 28% and 7% in Dong Thap site. The survey households in Can Tho located in suburban areas, so it is easier for the people to access not only education but also other updated information.

For the non-biogas user group, although the survey households in Hau Giang had highest number of member s who have not attended any school but it was highest percentage of people attending high school and university. It could be more people at the survey households of the Hau Giang site, at the time of the survey, falling in the age of university level. As a result, the households have to spend on their children's university education expense that could account for a large proportion of their household income; therefore they might lack the budget to build a biogas plant.

For the biogas masons group, most of them are freelance masons so that their education level was not high. There were 67% of the masons with secondary school level, 22% high school level and 11% primary school level. The insufficiency in education of the masons could affect their ability on the knowledge transfer and to access advanced technology while such comprehension is important to the promotion of biogas technology on a large scale in the region.

3.3.2 Living standards

The survey households' revenues come from various sources at both the biogas user and the non-biogas user groups. Most of the survey households are located at the rural and suburban areas that could be divided into three groups of income sources (i) from the cultivation, (ii) from the husbandry, and (iii) from other sources. The sources of main income were not similar between the group of biogas users and non-biogas users. In the group of biogas users, the sole cultivation households took 35%, the husbandry households 21%, and the other households (working in other sectors) 44%, while these values are 32%, 45%, and 23% respectively in the group of the non-biogas users.

Concerning this survey, the housing quality could be classified based on farmer's house types. In the MD, traditional houses are built on a condensed soil floor with nipa or coconut leaves, bamboo and wooden poles. At present, as a housing category, only poor people stay in this type of houses. The people with middle income build the house with brick wall but the roof made from tile or corrugated iron. Rich people build the house with brick wall and fixed roof by concrete. These three types of houses on thatched house, tile/corrugated iron roof house, and fixed roof house were applied to classify the living standard of the households in poor/low-income, middle-income, and high-income, respectively.

According to the survey result, the household living standard of the biogas user group was better than that of the non-biogas user group. In the biogas user group, there were 38%with high-income, 52% with middle-income and 10% in poor conditions; while there were 23% households in high income, 61% households in middle income and 16% households in low income in the non-biogas user group. There could be two possibilities to explain the difference in the living standard among the groups.

- The first possibility: the households of the biogas users classified as in high-income group could be poor before they have the biogas plant construction, but after the biogas plant construction financially supported by the project, they could make use the benefits of biogas application. These households could save money for energy and get more income that help improve their living conditions.
- The second possibility: the households of the biogas users classified as in high-income group could be rich before they have the biogas plant construction. Therefore, these households have financial ability to construct a biogas plant without the financial support from the project.

For the biogas user group, 29% of the households were in poor living standard at the Hau Giang site, but these poor households had constructed biogas plants due to the support from the biogas fund support project. In fact, the project VIE020 was implemented from June 2006 to March 2010 in Hau Giang, and one of the project objectives is poverty reduction for the households located within the project area.

Making a comparison of valuable properties in farmers' households between the biogas and the non-biogas user group, there were similar values of 40% households owning a television set, 40% with motorcycle and about 20% households owning a fridge. Due to high electricity cost and the shortage of electricity in the dry season, many households did not buy a fridge, and it could explain why the number of the households owning a fridge is low. No biogas-fridges were recorded at the survey households. In addition, 16% of the non-biogas user group and 25% of the biogas user group had no valuable properties such as television or fridge.

Another criterion representative for living standards of the households is the electricity network. Among the survey households at the three sites, only two households at Hau

Giang were not connected to the electricity gridline. On the other hand, only 2% of the households at all of the survey sites was without electricity. This result is lower than the number reported by the CPHCSC (2010) that the electricity networks cover 96% and 95% of the households at national and rural area scale. That is, according to the report, the electricity networks did not cover 5.4% of the households at the rural area.

In Vietnam, electricity supply depends much on hydropower that took 32% of the total electricity capacity in 2007 [ECOFYS, 2009 cited from ADB, 2009], leading a lack of electricity at the nationwide scale in every dry season. The national policy is to give a top priority in supplying electricity for industrial and service sectors mostly concentrated in the urban areas; therefore, the rural areas face a big problem of electricity shortage especially in the dry season. Application of biogas for lighting could be a promising solution to the electricity shortage in the rural areas of the MD and other rural areas in Vietnam.

Water plays a key role in all human activities in the MD. Water from a dense network of rivers and canals is used for transportation, aquaculture, plant production, industry, and residential activities. Annual flood comes and re-supplies alluvial soil that improves soil surface after exhausted from previous crops. Many plant crops start at the beginning of rainy season. Therefore, water management in the MD is crucial to controlling and protecting the water quality that should be paid high attention to by every local household.

The survey on sources of household's water consumption showed that more than half of the survey households got water supply from water supply stations - 65% of the group of biogas users and 68% of the group of non-biogas users. The results are much higher than the values from the tap water supply in nation scale. CPHCSC (2010) reported that 64% of households at urban areas and 9% of households at rural areas got tap water supply from pipe network. The highest value of tap water supply was concentrated at the Dong Thap site and the lowest at the Hau Giang site for both groups. It is a miracle leap on clean water supply at the Dong Thap site as one hundred percent of the households was known to use water from canals in 1999.

At the three survey sites, a relatively large number of the households still use water from canal - 16% of the biogas user group and 13% of non-biogas user group. Through rainy season, farmers store rainwater in the ceramic jars to drink for whole year, but for other activities such as clothes washing, dish washing, bathing, etc. farmers mainly use the canal water. Especially in the dry season, there is no rainwater, and the canal water turns to be the main source for all human activities in the area. It means any pollution from water sources will directly affect human health in the MD. The higher number of households using water from canal was concentrated at Hau Giang in both survey groups is typical for water supply situation in the rural areas in the MD.

In the survey sites, there are some of wells installed at farmer households. In fact, 20% of the biogas user group and 19% of the non-biogas user group have a well while this value was recorded in 49% at national scale [CPHCSC, 2010]. In the MD, due to water aquifers contaminant of high iron, chloride and arsenic [Do et al. 2000], the depth of wells could be reach 100 m underground. However, by high investment cost of well drilling, not all wells drilled up to recommended depth but most drilled in 60 to 80 m. By shallow drilling, wells could not supply water in good quality that caused of risk on farmers' health.

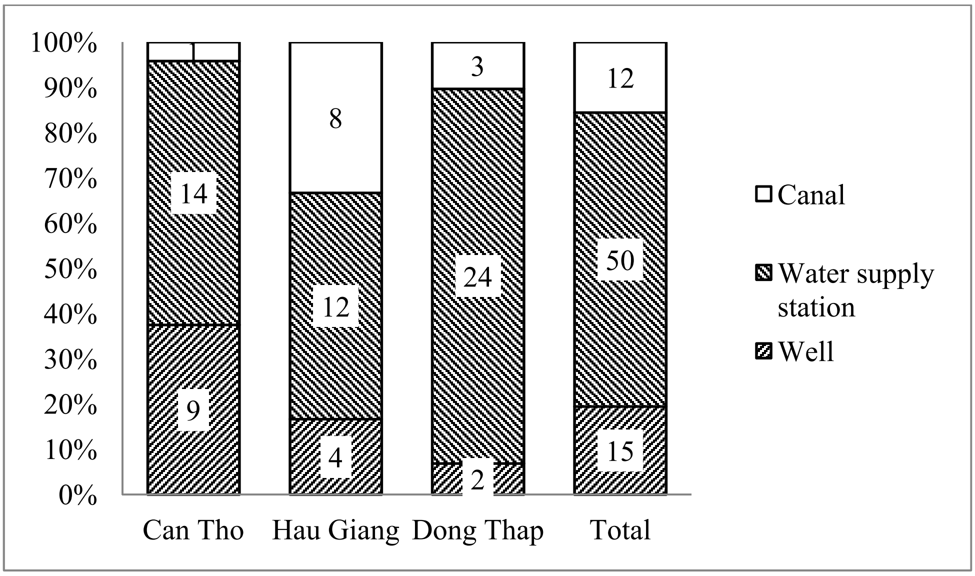


Fig 3.1 Sources of water-use at surveyed biogas user households

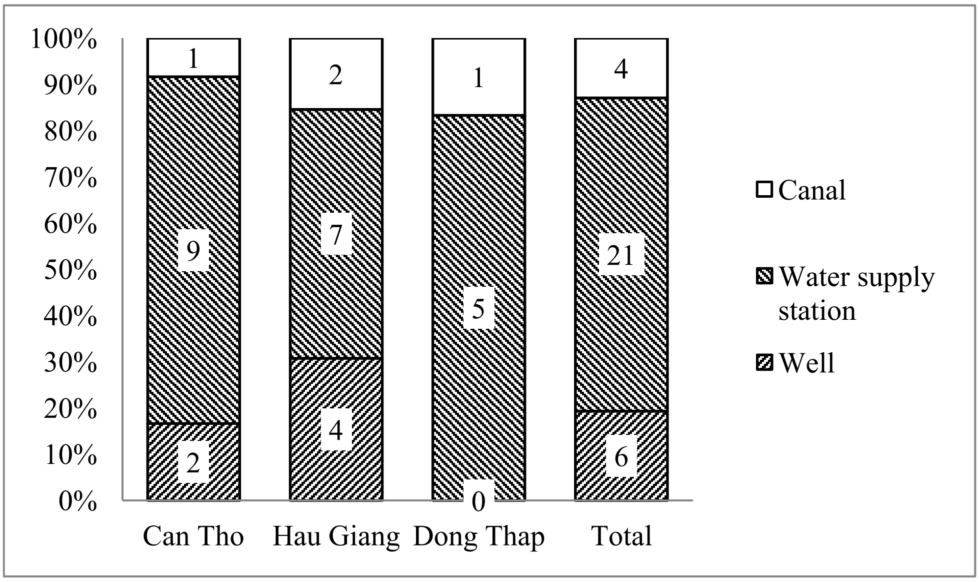


Fig 3.2 Sources of water-use at surveyed non-biogas user households

Within the biogas user group, there were more than 70% of the households in Can Tho and Hau Giang available with the VACB farming system. By contrast, due to most of the household in Dong Thap produce rice powder, only 24% of the survey households have integrated VACB model.

For the VAC farming system presented in the non-biogas user group, more than 80% of the households in Can Tho and Dong Thap available on this model and nearly 50% of the households at the Hau Giang site. The data on the number of the VAC model presented at farmer households showed a promising scenario to develop a new VACB model in case these farmers have a chance to install a biogas plant.

3.3.3 Summary and conclusion of the social and living conditions

According to this survey, there are summarize of the social and living conditions of the survey groups as follows:

- The average number of members per household is up to 5 persons, family size at the group of biogas users higher than that of the non-biogas user group.
- The principal educational level is secondary school, the people from the group of biogas users are higher education than the group of non-biogas users, and the educational level increases from rural to suburban area. Because of a limited educational level of the local people, the biogas programs should pay attention to apply suitable and frequent communication methods to widespread the information on biogas plant technology to the local people.
- Most of survey households were in good living conditions. More than half of the survey households lived in the house with brick wall but the roof was made from tile or corrugated iron. Almost the survey households were covered by electricity network, except some of the households in the rural sites.
- Some of the survey households used water from the surrounding canals for their activities, especially in the rural areas. The water from the canals is unhygienic due to plenty of pollution sources discharging from aqua-agricultural activities to the canals.
- Some of the non-biogas user households had main income from husbandry, but they have not yet invested in the livestock treatment plant.
- Application of biogas for lighting is a promising solution to the electricity shortage in the rural areas of the MD in dry season.

3.4 BIOGAS USERS SURVEY RESULTS

3.4.1 Identification of biogas plants

Among 77 biogas plants constructed at the three survey sites, the oldest one was built in 1998 at the Can Tho site, and the two youngest ones have just built for one year at the Can

Tho and Hau Giang sites. The total number of biogas plants constructed by year is presented in Figure 3.3. This figure shows the number of the biogas plants tends to increase in recent years due to some biogas support projects implemented in the MD.

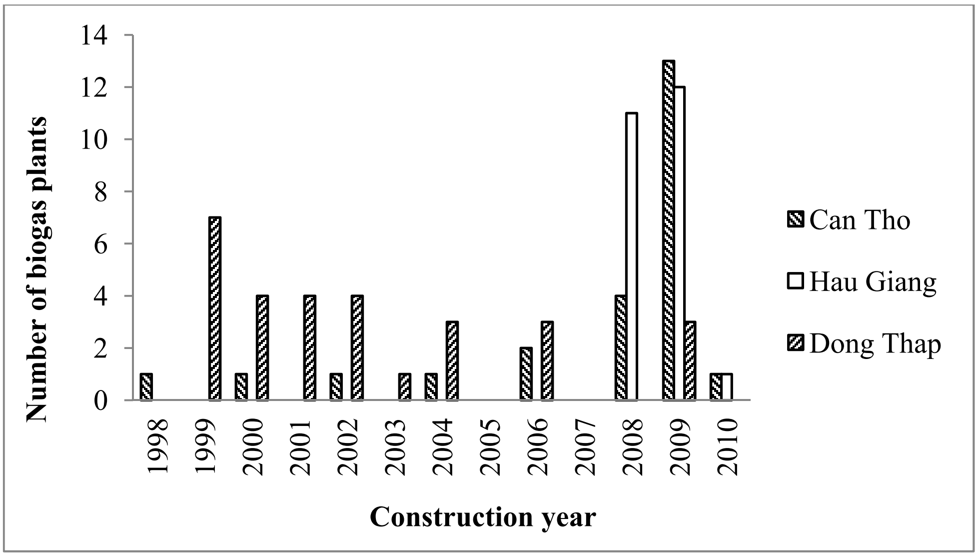


Fig 3.3 The building time of the surveyed biogas plants

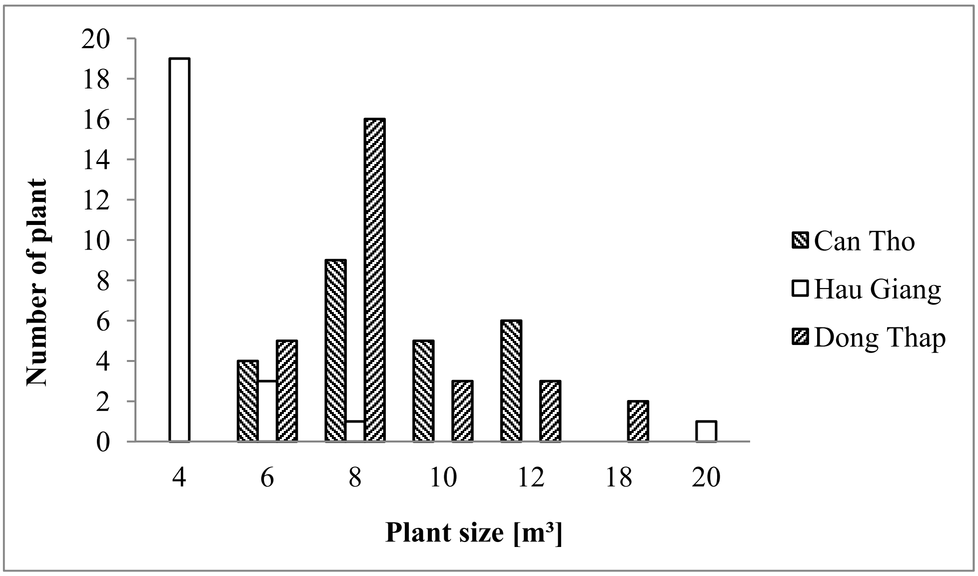


Fig 3.4 The volume of the surveyed biogas plants

The survey results also indicated that the popular volume of the biogas plant was 8 m^3 (34%) and concentrated in the Dong Thap site where farmers raising pigs with by-product from rice powder processing (Figure 3.4). In the rural area of the MD, commonly, farmers raise pigs in small scale of 6 to 10 pig herds so that the volume of biogas plant was 4 m^3 (25%), which is smaller in comparison.

In respect of biogas plant types, the TG-BP plants take large number of 43%, the PE digesters of 18%, the KT2 of 14%, and 23% of the EQ1 and EQ2. There is one household had a self-made biogas plant built by the local masons. This result clearly confirmed there are five popular biogas plant types having been applied in the MD.

Most of the biogas users in Hau Giang had support from the biogas project (92% of the survey households), while it is 75% of the survey farmers in Can Tho site, and 55% of the survey households in Dong Thap got financial support for their biogas construction. The number of the biogas plants were built at each survey site reflects the activities of the biogas support projects at these sites. In Dong Thap, it was clear that the project TPD has introduced the TG-BP plant model to the farmers, and it was recorded that 97% of the survey households have built the TG-BP plants. The VIE020 project has introduced the EQ1 and EQ2 biogas plant models in Hau Giang site, and 75% of survey households have built the EQ1 and EQ2 biogas plants there. In Can Tho site, the biogas projects have mainly supported the installation of the PE digesters (50% of the survey households), and another SNV project has supported the farmers to build the KT2 biogas plants (38% of the survey households).

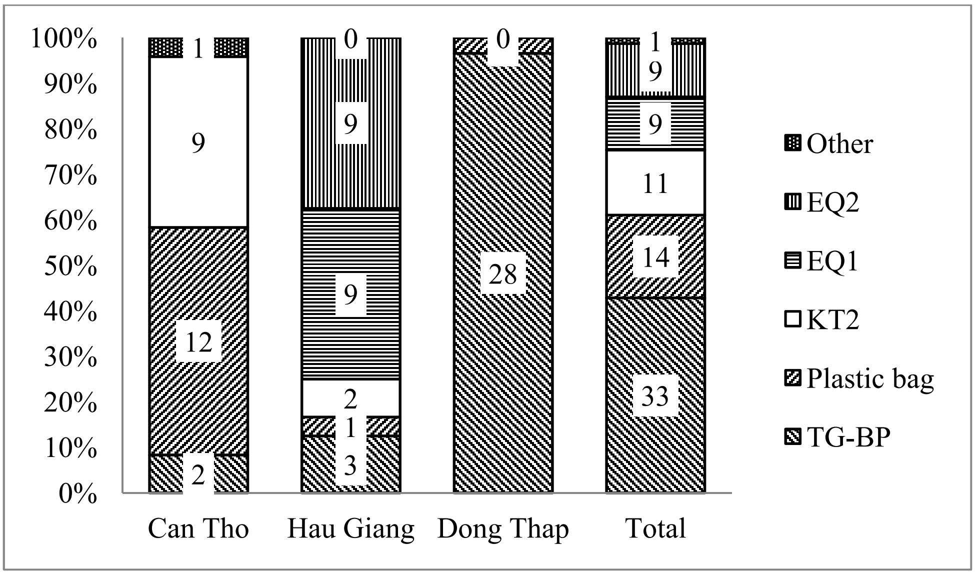


Fig 3.5 Types of surveyed biogas plants

In recent years, many farmers have been not only informed of biogas technology but also aware of the benefits of biogas plants. For the reasons of constructed a biogas plant, most farmers mentioned on the benefits of the biogas plant such as hygienic conditions (37%), saving energy cost (34%), reducing bad smell (17%), less of disease (1%), and saving the fertilizer cost (1%). Moreover, the farmers also mentioned the requirement of the local authorities on biogas plant construction to some households raising livestock (11%). In fact, there is one key point recorded is a high number of self-built biogas plant households are due to the enforcement of the local authorities in Dong Thap and Can Tho sites. The local authorities' enforcement on biogas plant construction at pig raising households mostly happened to the suburban areas (the Dong Thap and Can Tho sites) but not in the rural area (the Hau Giang site). This could be because the suburban people usually have small piece of land that is more sensitive by smelling from their neighbor livestock raising than the rural people who live far from one another.

With respect to the hygienic condition, the group of biogas users were interviewed how they had treated the livestock waste before they constructed the biogas plants. In previous time, most of the households had discharged the livestock waste directly into open water sources nearby their houses (79%), 11% of the households had discharged the livestock waste into their fishponds, 5% of the households had applied the waste as fresh manure for planting, and 5% of the households had treated the waste as compost.

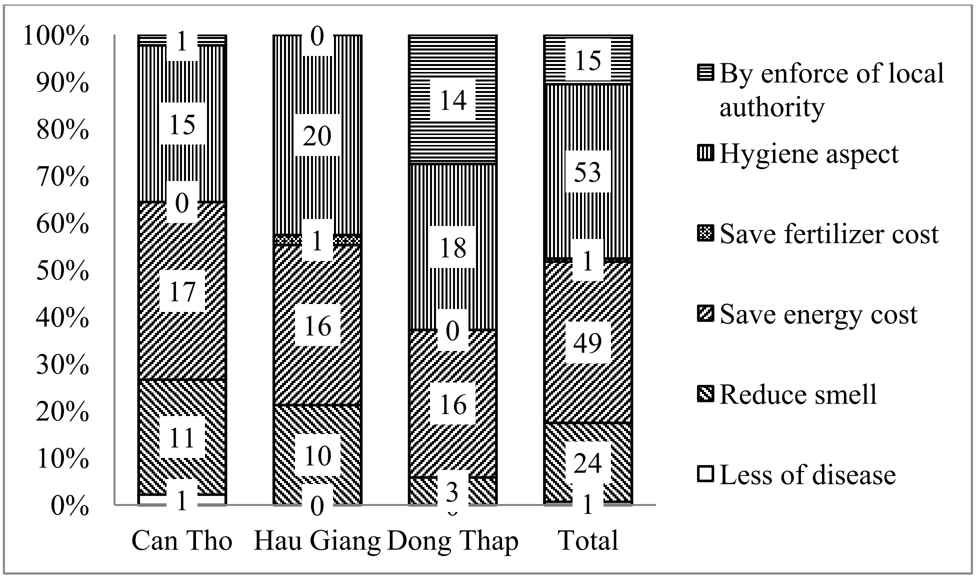


Fig 3.6 Reasons of biogas plant building

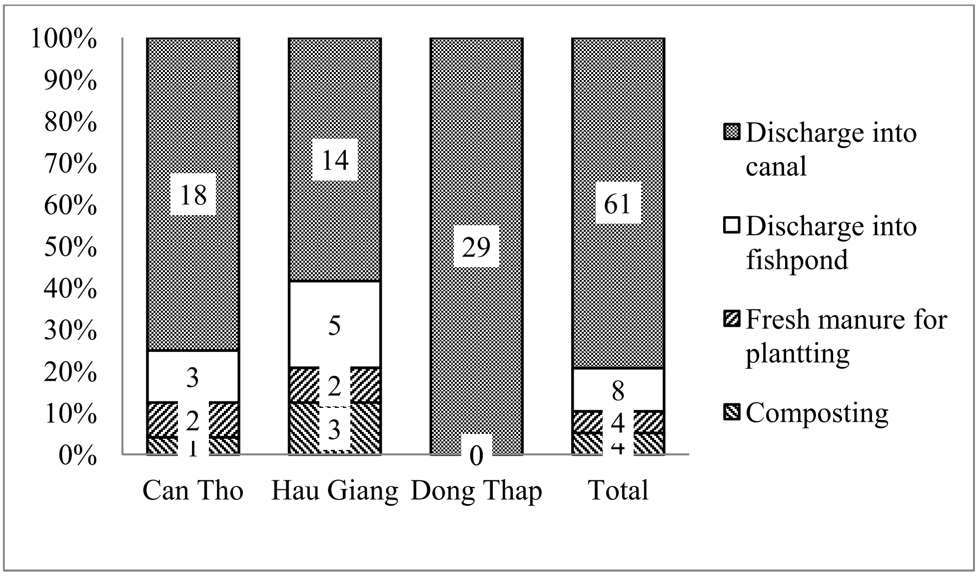


Fig 3.7 Treatment of livestock manure before construct the biogas plant

The survey results showed that 100% of the households in Dong Thap site had totally discharged the livestock waste (and the human waste as well) into open canals. There were 75% of the households in Can Tho site having discharged the livestock waste into canals while only 58% of the households had discharged the livestock waste into canal in the rural areas in Hau Giang site. These results look unbelievable due to less awareness of people in the suburban areas compared to the rural areas. The abnormal trend could be explained by the feedback from the livestock owners' neighbors. Among 77 survey households, only some cases of neighbor's complaint were recorded in Hau Giang site. In Can Tho and Dong Thap, there were no complaints recorded, and it could be because of no complaints, the livestock owners did not take much care on application of livestock waste treatment. They just discharged the livestock waste freely into open canal.

For the information sources on biogas technology which available for the farmers' access, most of farmers got information through the project staff (55%), the next information source was farmers' neighbors (31%) and the rest one was public media (14%). The results showed that there was less effect of public media on the biogas information and propaganda in the MD. This low value is due to a limitation of mass media device and communication program at the rural and suburban areas. By minimize these weaknesses, the biogas information would spread on large scale to farmers more effectively.

3.4.2 Construction of biogas plants

From the respondents' information, the biogas plant has been constructed by the biogas masons group but not by a construction company. In fact, each of the biogas support projects has trained its own biogas masons who already had skills and experience on construction works. The biogas masons built the biogas plants and got salary as contracted with the project. Besides the biogas construction work for the project, the biogas masons also built biogas plants for some farmers who would like to build biogas plants by their own finance. After the completion of the projects, the trained biogas masons formed groups of freelance biogas masons (with other persons as assistants) to continue their biogas construction work when needed.

The biogas construction cost includes fees of construction materials, labors and the biogas appliances. In this survey, the budget that the households distributed to build their biogas plants was inquired. Among the group of biogas users, there were 73% of the households funded partly by a biogas project. Many of the households at the Dong Thap site who did not receive any support from the projects have invested on their biogas plant construction at their own expenses (45%).

Within the biogas projects, most of the beneficiary farmers had to follow the building instructions given by the project staff and/or project biogas masons. However, the farmers had right to distribute their comments on the biogas plant volume. There were 12% of farmers decided on their biogas plant volume by their own knowledge, 3% based on the experience of other biogas owners, and 8% from other sources of information. The less professional choice of biogas plant volume gave some negative effects to the biogas plant operation and maintenance later on. Acting as a treatment method of livestock waste, the volume of biogas plant depends on type and quantity of livestock herd. In case a farmer makes a suggestion on the biogas plant volume or he gets advice from other biogas owners, the suggested volume can be not appropriate to the treatment efficiency of the plant. By chance, most of the biogas plants with self-chosen volume at the Can Tho and Hau Giang sites are PE digesters which were installed with 10 m³ volume. But the self-chosen volume that has been applied on the TG-BP plant model has caused pollution at the survey households at the Dong Thap site. In fact, to improve the pollution situation at the local area, the authority has issued a decision on requirement of biogas construction at livestock raising households. However, due to economic matter, some farmers only invested on small biogas plant volume to accord to the decision even though they raised more livestock than the biogas plant volume constructed. Consequently, these biogas plants, shortly after use, became overloaded with the livestock waste input, causing the pollution worse at some households in Dong Thap site.

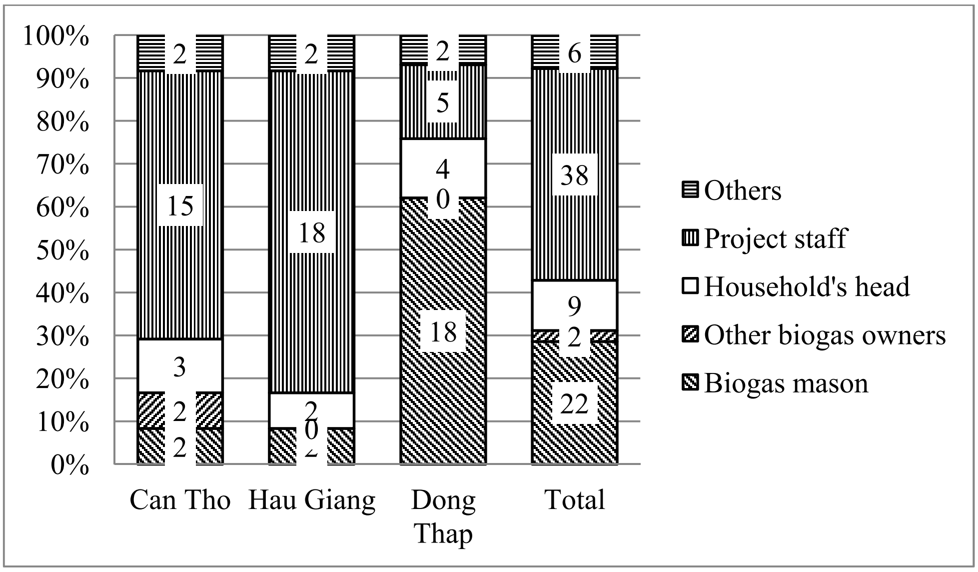


Fig 3.8 Consultant for biogas plant volume

For the reasons to choose the construction place, most biogas plants were installed nearby pigpens (77%). If a biogas plant is built to treat pig waste of an existing pigpen, it is really a hard work of construction due to dirty area around the pigpen location. In most of the cases, the biogas masons did not cover the clearance and the earth-works. They signed the contract only for construction works including building, installing the inlet and outlet pipes, gas pipe, and connect biogas devices, etc. Farmers had responsibility on the jobs of the clearance and the earthwork to prepare the construction site.

The beneficiary received either loan money with low interest or partial fund support in some biogas support projects. It means the beneficiary also contributes part of the investment cost to build a biogas plant, and they have to take care for their biogas plants construction. The survey showed that there were 95% of the survey farmers having supervised the construction work of their biogas plants. Only few households at the Hau Giang site did not take care for the biogas construction work because they had no time and fewer members at their families.

Assessing the suitable volume of the biogas plant, almost respondents (96%) informed that their plant volume is appropriate to their household usage, only 3% complained that their biogas plants are too small, and one household said that his biogas plant is too big. In this matter, farmers mainly base on the gas production from their biogas plant to examine for the suitability of biogas volume. For example, in case the farmer observed that his biogas plant produced less gas, he could comment that it was a small volume of biogas plant, and vice versa. If the household got enough gas for cooking, he thought the biogas plant volume was appropriate.

Similar to other constructions, generally the biogas masons are responsible for providing a construction warranty to the biogas owners. Concerning the biogas construction warranty, 66% of the survey households had signed warranties. Almost these households built the biogas plant within the support projects. The warranty for the biogas construction is normally a one-year warranty, but only for concrete biogas plants. There were 34% of the households had no construction warranty; these biogas plants were built not involved in any biogas support projects. There are some reasons why farmers did not have such a warranty, for instance, there was no warranty for PE digesters, the biogas owners did not know about the warranty or just simply they did not care about it. In fact, most of the biogas user households who have not received warranty had no concern on this matter since they already know the telephone number of the biogas mason for further contact.

According to the farmers who signed the warranty for the biogas plant construction, only 22% of them have met some problems regarding their biogas plants during the warranty time. Most of the problems happened not on the biogas plant body but on the outside devices such as gas pipe, biogas stove, etc. Nevertheless, quality of maintenance service was highly appreciated by the biogas user households. In case of any problems happening under the warranty, the farmers just made a phone call to the biogas masons in charge, and then they would rapidly response within three days.

3.4.3 Operation and maintenance works on biogas plants

In almost biogas support projects, the biogas owners were trained on biogas O&M. The project staff and/or the biogas masons would provide training to the biogas owners. There were 88% of the biogas user households gained knowledge on the biogas O&M. It seems some groups of the biogas masons did not fully support to the biogas owners. According to reported from Huynh (2003), the project TPD in Dong Thap not only provided loan credit for the farmers to build the biogas plants but also trained them on biogas O&M, especially on operate the biogas plant in flood season. The biogas project in Hau Giang required at least one person at the household which want construct the biogas plant attend the biogas construction work. By that way, the household knows the biogas O&M works well. As a result, the biogas user households got skills on O&M works (41%) and gained more knowledge on using biogas (57%), hygienic conditions (1%) and slurry using (1%) as well.

The biogas plant quality at each household was assessed through its operation process. The biogas users were required to evaluate their biogas plants quality based on any failures happened in the operation time. Regarding 77 survey households, 36% of the households recorded some failure happened, while the other 64% had no problems with their biogas plants using-time. The biogas failures made some of the biogas plants stop operation at times, which affected the biogas using of the households negatively, especially in case the biogas user households have stored no fuel for their cooking.

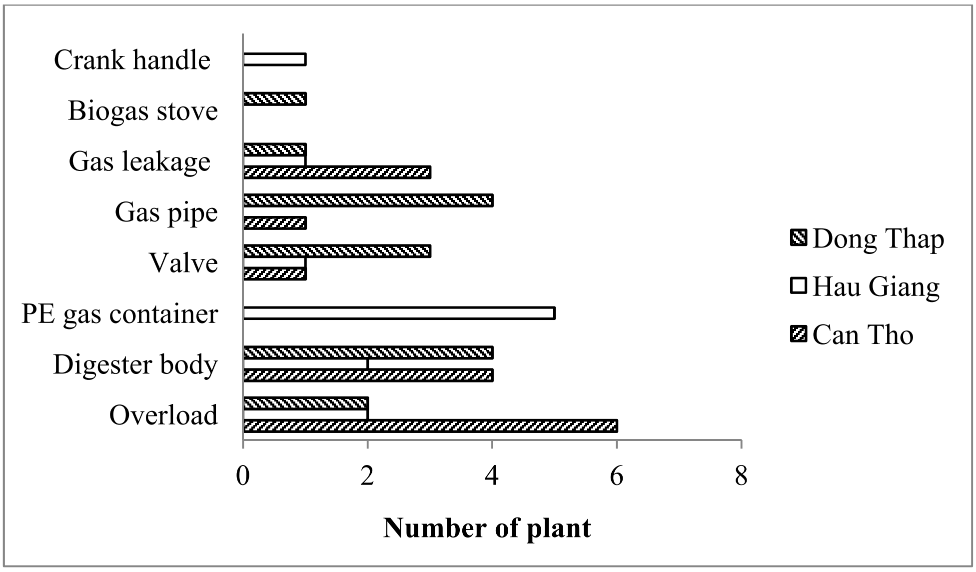


Fig 3.9 Types of biogas plants failures

Among the happened failures related to the biogas plant operation, most of damage was due to overloaded input, digester body (with 80% from PE digester), PE gas-holder, valve, gas pipe, etc. With the O&M guidelines, there were 58% of the farmers facing the failures could fix their biogas plant failures by themselves. Compared to 60% recorded failure of biogas plants, it seems almost biogas plants' problems were quickly repaired. Yet 42% of the farmers who do not know either they can fix their biogas plant failures or not, lived in the Can Tho site where they easily find out a biogas mason who can fix their biogas plants, so they did not care much about the maintenance works.

Regarding the maintenance works, most of the farmers paid attention to cleaning biogas stove, wetting digester trap, taking sedimentation clearance, etc. All of the survey households informed that they had no input leftover from their foods to the digester but they fed it to the pigs.

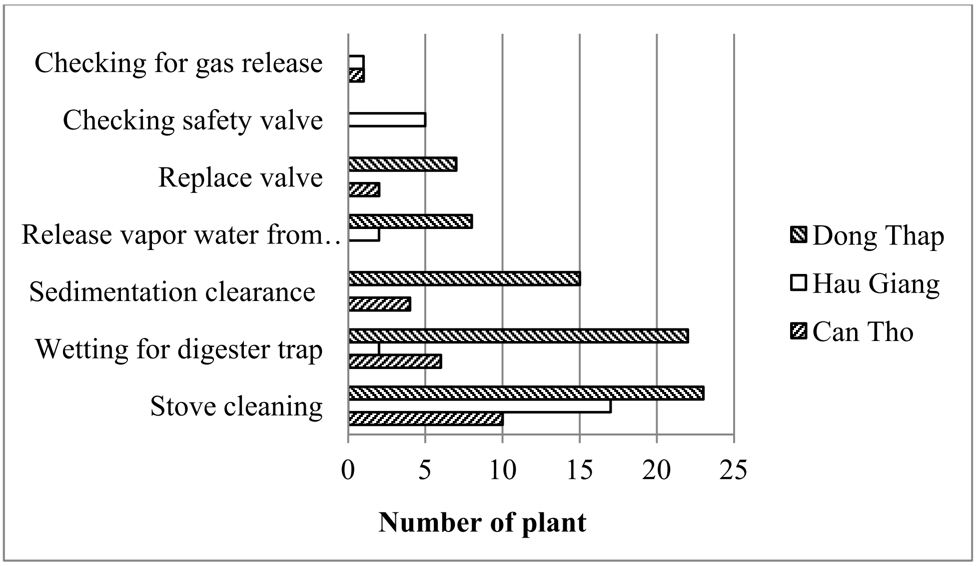


Fig 3.10 Types of maintenance activities

The survey results showed that highest number of farmers in Dong Thap site could and could not fix the biogas plant problems, 66% and 14% respectively. These values reflect the real situation at this study site. In fact, the farmers in Dong Thap had chance to attend an O&M training course which offered by the biogas support project. Furthermore, about 35% of the people at this site were well educated with high school and university level, while these values in Can Tho and Hau Giang sites were approximately 45%.

For the pigpen cleaning procedure, farmers do this job combined with pig bathing. It is one or two times per day depending on the weather. The person who in charge of pigpen washing was similarly between man and woman (38%), and the rest 24% was both man and woman in the family. However, there was a difference on gender of the person in charge of cleaning the pigpen between the suburban and rural areas. In the rural area, more women (63%) were in charge of pigpen washing, while in the suburban area this job was shared by both men (33%) and women (25%), even any member of the household did the washing job at free time (42%).

3.4.4 Biogas application

Concerning to the survey households, almost they applied biogas for sole cooking, not for lighting or power generator. From the respondents, the project staff and the biogas masons did not inform them of the biogas lighting but only introduced the biogas stove for cooking. Here are some reasons of such a choice of biogas using:

- For cooking: all types of the biogas plants constructed in the MD are applicable for gas cooking, regardless of gas pressure/volume of the plant or the types of gas-holder.
- For lighting: by special structure of the biogas lighter, it needs high gas pressure (around 40 cm water head) that could enforce biogas through the gas injector jet of the biogas lighter. This requirement is satisfied only in the concrete fixed-dome plant such as TG-BP and KT2 models. The produced biogas from the PE digester or concrete plants but with PE gas-holder (EQ1 and EQ2) could not apply for lighting due to low gas pressure (only about 20 cm water head).
- For power generator: to get enough gas for generator, it requires the fixed-dome biogas plants (for high pressure) and consists of a sufficient volume of plant.

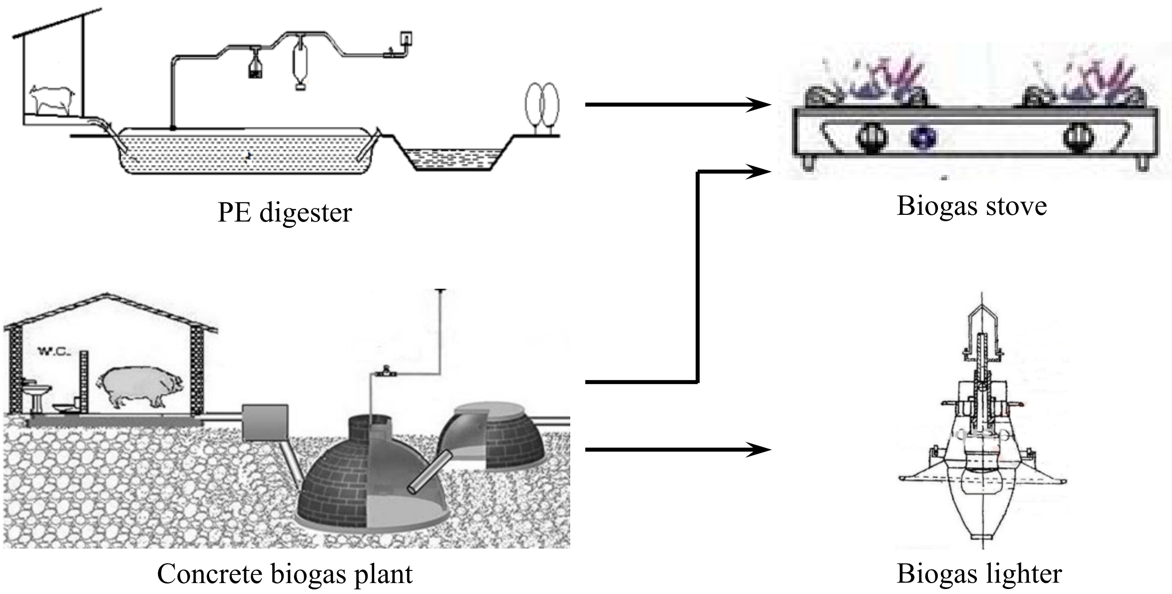


Fig 3.11 Types of biogas plant adapted to biogas cooking and lighting

Responding to the question on the feeling of cooking with biogas, 96% of the biogas user households satisfied with the biogas cooking. Especially 100% of the survey farmers at the Dong Thap site were satisfied with biogas cooking. Be mentioned that 97% of households in Dong Thap site have built the TG-BP biogas plants; by completely airtight this biogas model supply the biogas in good quantity and quality to the farmers.

Farmers who were not satisfied with the biogas cooking (4%) mentioned two reasons of their no satisfaction that it was low temperature (20%) and unpleasant smelling (20%), while the others did not give a clear reason. In respect of the reason of low temperature, only the household who owns the PE digester complained of this matter due to the red firelight appearing at the stoves, instead of the blue firelight. Of course, due to the gas-holder made by PE bag, it could not supply a high pressure of gas, which would lead to low temperature for cooking. For the reason of smelling, it is a common reason at most of the biogas user households due to only one household in Hau Giang installed the gas treatment unit but this household was demonstration site. By cooking with the un-treated biogas, the existing H_2S component will cause corrosion of the metal parts of biogas devices and smelling while burning the gas. In the past, there was no suggestion from the project staff and/or the biogas masons on H_2S treatment. In case only applying biogas for cooking, it is possible to skip the H_2S treatment, but in case of applying biogas for other purposes such as lighting and power generator, it is necessary to install H_2S treatment to maintain the lifetime of biogas using devices [Nijaguna, 2002].

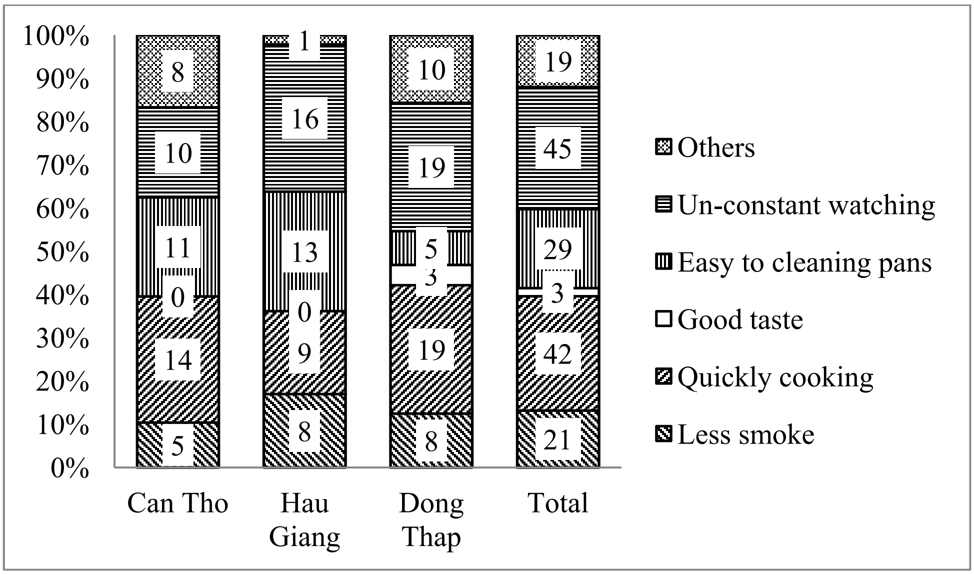


Fig 3.12 Reasons of satisfy on cooking

By multi-choice of satisfaction reasons with biogas cooking, two largest options are un-constant watching and quickly cooking of 28% and 26% respectively. Then 18% of the farmers got satisfaction from cleaning pans easily after cooking, and 13% liked cooking by biogas because of less smoke. Farmers based on their experience of the convenience of biogas cooking compared to their conventional cooking materials such as wood or rice straw to give their satisfaction reasons of biogas cooking. However, there is an economic reason that the farmers also found out while cooking by biogas.

The operation of the biogas plant was evaluated base on assessing the produced biogas. A biogas plant is considered to operate ineffectively if it produces little biogas. The poor operation of the biogas plant depends on some facts such as defects on the plant body, leakage on the gasholder, bad digest of microorganism inside the digester, inappropriate gas volume, etc. Some of the survey households complained about the biogas shortage - 12% in total. The biogas shortage of the households was due to a decrease in the number of their pigs caused by blue-ear disease, the variation of the pig market price and the rising price of pig feedstock. Up to date, farmers have no solutions to this problem. Therefore, it could be an optimize solution to the biogas shortage by feeding some other input materials into the biogas plant to maintain the volume of biogas. On the other hand, 52% of the survey households got extra gas. They had extra gas, but they had no biogas appliances to use the excess gas, only biogas stove. In the MD, most people apply biogas for cooking, not for lighting or other fuel consumptions. The explanation of this could be that when constructing the biogas plant, the biogas masons have not introduced biogas lighting because most of the households have already covered by electricity network. Nonetheless, the masons did ignore the fact that the rural areas of the MD are frequently on lacking of electricity, especially in the dry season when there is not enough rainfall for the operation of the hydro power plants. It is essential to introduce biogas lighting to biogas user households in the MD, and this is a promising solution to consumption of the extra gas as well as to save the household expenses on electricity.

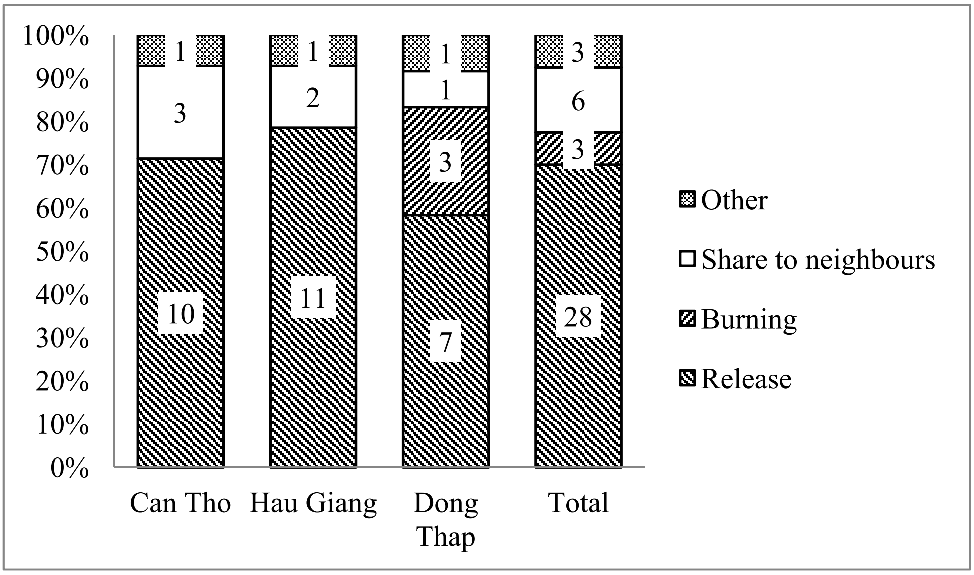


Fig 3.13 Solving of the extra gas

For the extra gas, there were 70% of the households released the extra gas into the air, 15% of the households shared the extra gas with their neighbors, 8% of the households treated the extra gas by burning (all of them located in Dong Thap site). By high content of methane inside, the released biogas could have negative impacts to environment, so it is good to treat the biogas instead of releasing them into the air. However, the farmers of the MD have not been trained or informed of the extra biogas treatment methods.

3.4.5 Hygienic impacts of biogas plants

In the MD, a biogas plant is applied to treat not only livestock waste but also human waste, which is largely useful for the rural areas where the hygienic condition is low. It was reported that only 39% of the rural households having latrines in Vietnam [CPHCSC, 2010], that is 61% of the rural households of the nation live in a limited hygienic condition. To promote the biogas plant installation, the projects staff and/or the biogas masons always announce a combined construction of the biogas and the human latrine.

According to the Vietnamese sanitary standards, a sanitary latrine is latrine without discharging human waste directly to open water sources. There are some types of the sanitary latrines in the MD such as the flush latrine[1] (mainly installed at the urban households) and the pit latrine[2] (mostly installed at the rural areas). To evaluate the effectiveness of the combined construction, the biogas user group was asked if there had already been any sanitary latrines constructed at their households before building the biogas plant. In average, the number of households having sanitary latrines before the construction of the biogas plant is rather high (48%). Within the group of biogas user households, the existing of sanitary latrines of the Can Tho site is the highest (54%), then the Dong Thap site (48%), and the lowest at the Hau Giang site (42%). This trend is normal because the survey areas in Can Tho are located in the suburban areas, while in Hau Giang the survey areas are located in the rural areas.

For those households already having the sanitary latrines, most of the survey households did not connect the latrine output to the building biogas plants. Nevertheless, among 52% of the households without the sanitary latrines, few of the households agreed to combine the biogas plant with the toilet. Only 30% of the household built their toilets in combination with the biogas plants. There was no important reason on such a disagreement from the respondents. The farmers have a common feeling that human waste could be worse than the livestock waste could, so they do not want to apply the human waste into the biogas plant and then use this biogas for cooking their food. The new biogas support projects that will be undertaken in the MD should pay attention to this point to save the budget of latrine building and improve the hygienic conditions of the region.

There were two reasons for a combined construction of the biogas plant to the sanitary latrine - saving on building a new separate latrine (58%) and following the advice from the project staff (42%). Many farmers knew that they would have a sanitary latrine with less investment cost by the combined construction of the biogas plant, instead of building a new latrine. A combined construction of biogas plant and sanitary latrine is an outstanding benefit of biogas application in the rural area where few farmers own the sanitary latrines.

Among 70% of the households who did not build their latrine combined to their biogas plant, 18% of them have already had latrines but their existing latrines were quite far from the location of their biogas plants and it was inconvenient to build a combined biogas plant in their cases. There were 50% of the households did not build their latrines combined to their biogas plants due to their habit of using sky-toilet[3]. The rest of the households (32%) known as "using sky-toilet" because the farmers did not want to mention this type of toilets

[1] The flush latrine is a latrine using water to flush human waste through a drainpipe to the septic tank
[2] The pit latrine is a simplest latrine with the hole in the ground and the floor plate installed above the hole
[3] A sky-toilet is a latrine located on a canal or pond in which human waste is discharged directly into the water body.

directly due to their inhibition. This unsanitary toilet has existed in the MD for a long time and it became a rural custom. Even the government had a plan to clear up all the sky-toilet in the rural areas at nation scale [_____, 1994], but it is likely hard to abandon such a type of toilet in the rural life of the region.

3.4.6 Using bio-slurry

Nowadays biogas plant is well known for both wastewater treatment and gas production. In addition, it's by-products can be applied as nutrient sources to aqua-agriculture activities. The bio-slurry[4] come out from the biogas plant is applicable as organic fertilizer to farmers' garden or dischargeable into fishpond for raising algae for fish-feed. In this case, it seems to be post treatment way for discharge from biogas plant.

By apply the bio-slurry as fertilizer to gardening or fish raising, the contaminant from the effluent will be minimize and less polluted to the received sources. In spite of the benefits of bio-slurry as mentioned above, less than half of the survey households (42%) had applied the bio-slurry to their farming activities. The highest percent of the households who applied bio-slurry at the Can Tho site (58%), while only few of the households at the Dong Thap site applied bio-slurry (17%).

Knowing the benefits of the bio-slurry, 38%, 22%, 25% and 13% of the households have used bio-slurry in types of fresh slurry, dried slurry, composting and others, respectively. The fresh slurry was the highest option because this application takes less labor time; the farmers collect the bio-slurry discharged from the digester and apply directly to their gardens or fishponds. However, this type of using is unhygienic by raw and liquid form. Application of bio-slurry in composting is the most safety for farmers to use bio-slurry but it takes more labor time. The survey results showed that more farmers at the Can Tho site applied bio-slurry in type of composting (36%) that is due to a higher educational level at the same site.

For the multi-choice question on the reasons of application of bio-slurry, the answers are to improve food quality (34%), increase crop productivity (28%), reduce expenses on fertilizers (21%), reduce pets (14%), and others (3%). These results reflect the types of farming system at each survey site. In the Dong Thap site where the people are more concentrated on rice-powder production, the bio-slurry was mainly applied to the fishpond, so the farmers only mentioned an increase in crop productivity and food quality. While at the rural areas in Hau Giang site, the farmers work in both agriculture and aquaculture, so the bio-slurry was added could reduce pets for planting.

For the reasons of no application of bio-slurry, two defined reasons and one undefined reason were recorded. There were 38% of the farmers did not know how to use the bio-

[4] Bio-slurry is the residue that comes out of the biogas plant as a remain of anaerobic digestion process.

slurry, and 9% did not believe in fertilizer effects from bio-slurry. These results showed that a relatively large number of farmers do not have knowledge of the benefits of the bio-slurry application. Consequently, there should be more communication information programs on the benefits of bio-slurry application rendered to farmers. There are 53% of the survey households were chosen "others" to the question; in this case, the "others" option that the respondents meant does not mean that the farmer did not like to use this type of fertilizer. It could be the farmer's conventional behavior of using inorganic fertilizers, but not organic fertilizers, in the MD. Especially in the case of biogas plant, because the organic fertilizer comes from livestock waste, the farmers have feeling on unhygienic to use such an organic fertilizer.

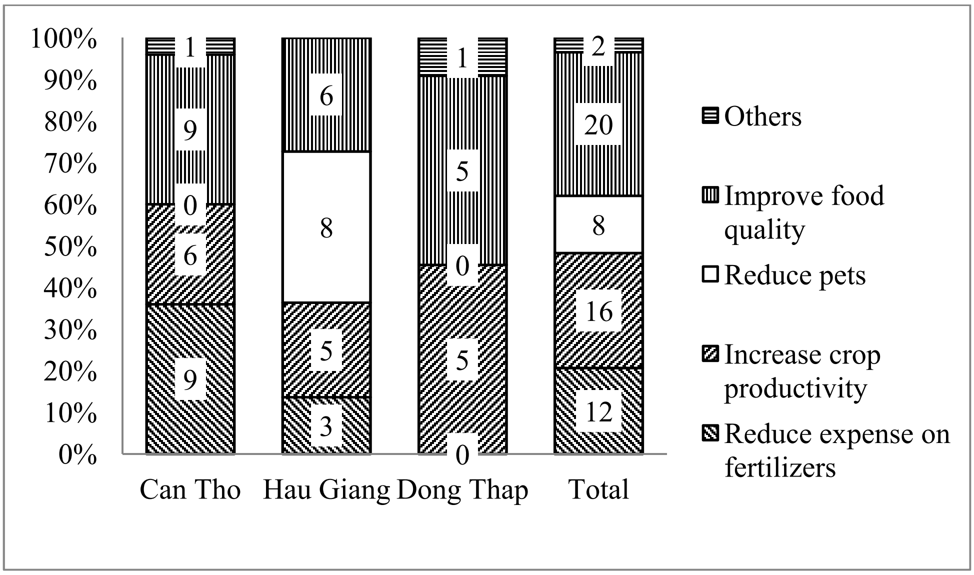


Fig 3.14 Reasons of apply the bio-slurry

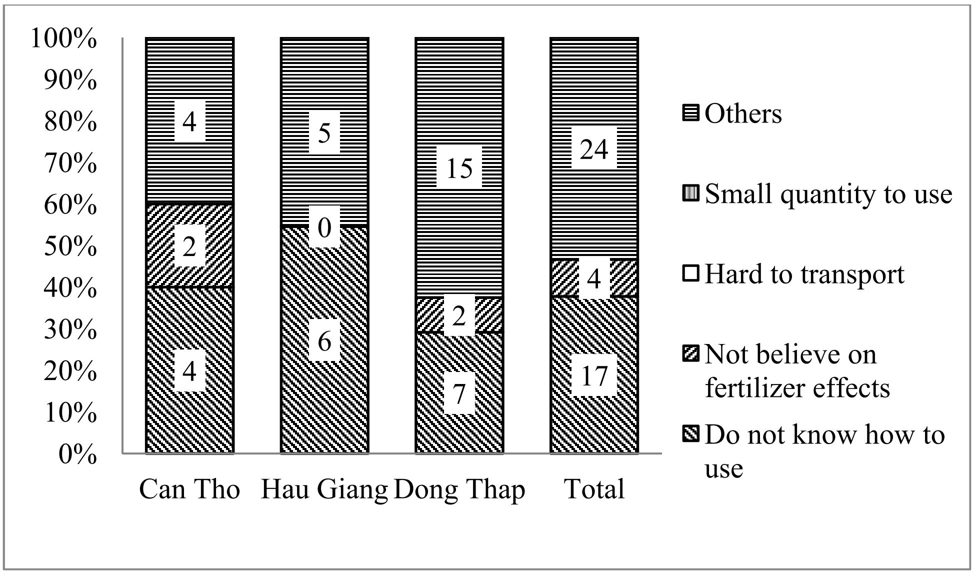


Fig 3.15 Reasons of not applied bio-slurry

For the bio-slurry outlet from the digester, in case the farmers did not apply it to their farming system, most of the farmers simply discharged it directly to an open canal, and only one farmer (2%) sold it to his neighbor. Indeed, 58% of the survey households said they discharged the bio-slurry into canals, and 40% said they treated the bio-slurry in "other" way. In fact, this question is rather sensitive and some of the farmers did not want to choose directly "discharge wastewater into open canal" option but "other", which is equated with "discharge into open canal".

3.4.7 Other benefits of biogas plants

The survey on farmer's expense on fuel for cooking in the case of the non-biogas plant users showed that each household paid from 250,000 VND to 350,000 VND per person for cooking fuel per year. The payments were for wood, coal, liquid gas, or electricity, which farmers used for daily cooking. This means that if a household has enough biogas for cooking; in average he saves 300,000 VND per person per year. This money value is rather big for a normal households at the rural area where people get low income if compare to other regions in Vietnam.

Furthermore, the application of biogas plant helps develop the livestock herds at the biogas user households. In fact, the scale of livestock husbandry in many biogas user households has increased significantly in the region since the biogas plant came into operation. Farmers feel safe to promote their livestock due to good treatment of livestock waste and good quality of gas for cooking. However, the survey results cannot clearly show a difference in the number of livestock before and after the construction of the biogas digester. The number of livestock is variance due to market cycle - the livestock herds decrease when high cost of foods or any disease happens and vice versa.

Besides the financial and environmental benefits of biogas plant, the biogas plant bring about the social benefits such as saving time for household members on preparing firewood for cooking, saving cooking time by quick cooking and less washing pots, etc. At the households applied firewood in the past, mainly women and children took part in this work; and most women are in charge of cooking at households in the rural MD.

By saving the time, women and children could apply their free time to other activities. These activities benefit them in various ways such as gaining more knowledge by reading newspaper or watching television, attending some social activities, relaxing, doing other activities like cleaning household, educating their children, or increasing income from doing gardening, etc. There were some of the farmers mentioning no comments on this question but they believed use this free time to do "no name" works at their households.

This survey showed that a large number of the biogas user households (56%) who were satisfied with the benefits of the biogas plant encouraged other farmers to build a biogas plant. In the Dong Thap site, only 24% of the biogas user farmers advised other farmers to build the biogas plant. This value could be higher but about half of biogas plants users at the survey households in Dong Thap built their biogas plants under the enforcement of the local authority.

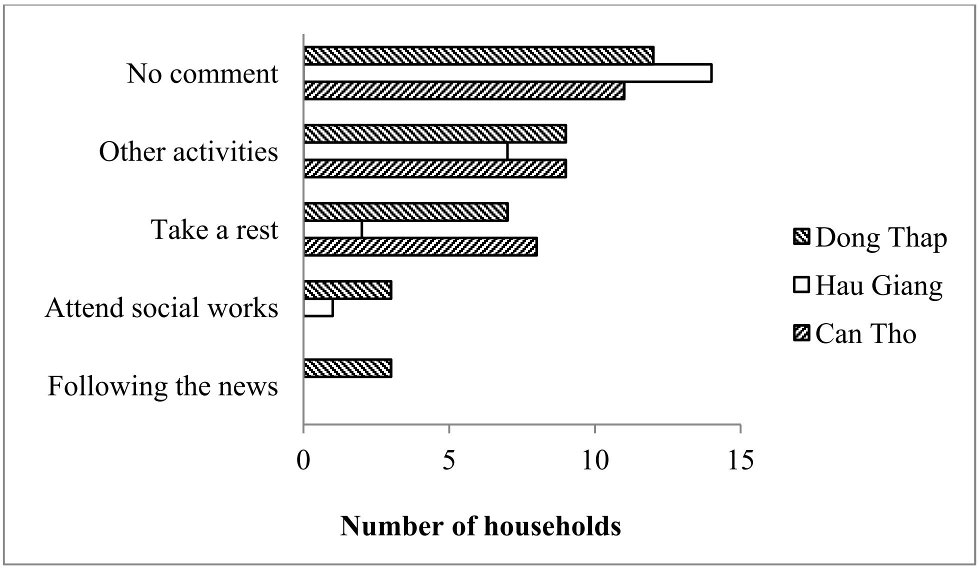


Fig 3.16 Activities at extra free time

In addition, 100% of the survey households mentioned that they would keep using their biogas plants due to the great benefits of biogas plant. One farmer in Hau Giang informed that he would stop using his PE digester model and switch to build a new concrete digester. This is a good potential to spread the application of biogas plants on large scale in the MD.

3.4.8 A summary of the interview results of the biogas users

- Few farmers like to apply the human waste into the biogas plant.
- The farmers have not been informed of the biogas treatment methods causing biogas applicant defects.
- The farmers did not apply any treatment methods to their extra biogas.
- Some changes have been made to the people's local habit on using the sky-toilet.
- Most of the biogas user households obtained the biogas information from the project staff or the local authorities.
- Almost surveyed households used biogas for cooking. The benefits of biogas plants are clear but the use of biogas in the MD does not reach the biogas potential. In fact, the biogas can be utilized for lighting, refrigerator, electric generators, etc. Therefore, there should be an introduction and promotion of the biogas application to farmers so that they can use biogas for various purposes other than cooking.
- Most of the survey households did not apply any gas treatment methods.

- Only the biogas stove has been introduced to the local people. They have not been informed of biogas lamp and other biogas devices.

3.5 NON-BIOGAS USERS SURVEY RESULTS

3.5.1 Living conditions

To check the potential of biogas application at the survey households, information on the types and quantity of their livestock was asked. Among 31 survey households, only three of the households (10%) had no livestock. Based on livestock herds, there were 81% pig herds, 11% poultry, and 8% cattle. In this survey, most of the households had from 4 to 10 pig herds, except the farmers at the Dong Thap site raised from 40 ÷ 60 pig herds per household. With a large number of livestock, the untreated pig waste has really become a big concern to the environment of the local area. Moreover, 71% of the households raised fish for eating and trading. It is easier for the farmers to apply bio-slurry into fishpond other than to their crops due to the custom of raising fish by human waste in the past.

Related to hygienic condition, the survey focus on how the livestock wastes were treated. There was 62% of the survey households discharged livestock wastes directly into open canals, 29% discharged into the fishponds and only 10% applied for composting. Nobody applied the fresh manure directly to their crops due to its "hot" and it may damage their vegetables, crops or plants [Dan *et al.*, 2004]. Three of the survey farmers (10%) mentioned about their neighbors complaining of odor. These three farmers live in the suburban area surrounding Can Tho where people usually have less land and know the livestock waste treatment methods.

In this survey, information on the sanitary latrines existed at non-biogas user households was asked. In average, the number of the households with the sanitary latrines was 39%. This value is less than the value recorded in the biogas user group (48%) before they construct the biogas plants; however, the value is in line with the recorded value from Vietnam Census that 39% of households at rural areas have their own latrines [CPHCSC, 2010]. The survey results also showed that there are the most sanitary latrines at the Dong Thap site, more at the Hau Giang site, and the least at the Can Tho site. This result sounds strange because the Can Tho site is located at suburban areas that are assumed to have many sanitary latrines, while at the Hau Giang site the survey areas are located at rural areas but there are more sanitary latrines than at the Can Tho site. Due to the small number of survey samples, it could not make any direct conclusions at this point.

A low number of sanitary latrines constructed by the non-biogas users could be a good economic starting point that will help widespread biogas application on large scale in the region. Among the families who have no sanitary latrines, some of them had the sky-toilet or even they had no latrine at their households. These farmers should be introduced a combined construction of biogas plant and latrine if any. By that way, the farmers save money on building a septic tank but they still possess sanitary latrines.

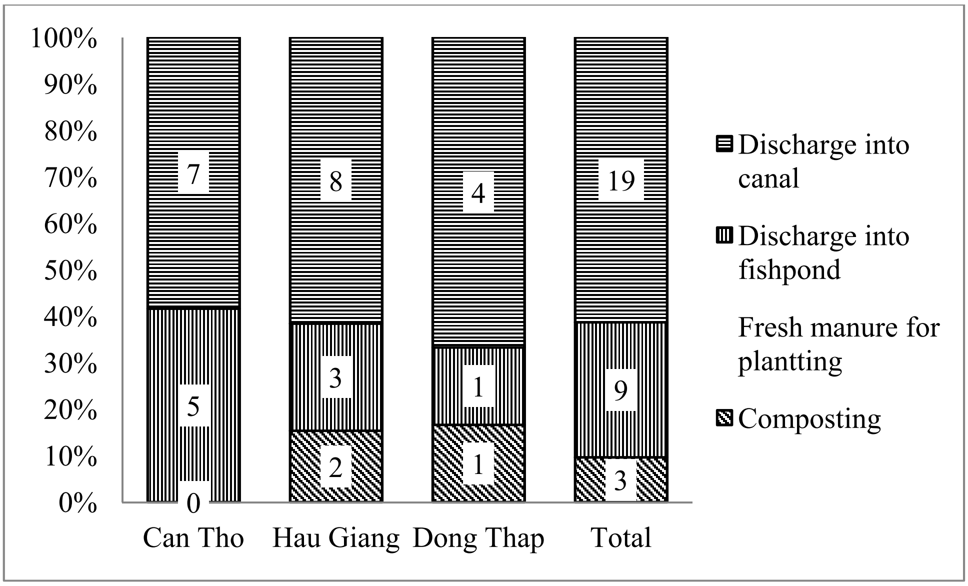


Fig 3.17 Treatment on livestock manure

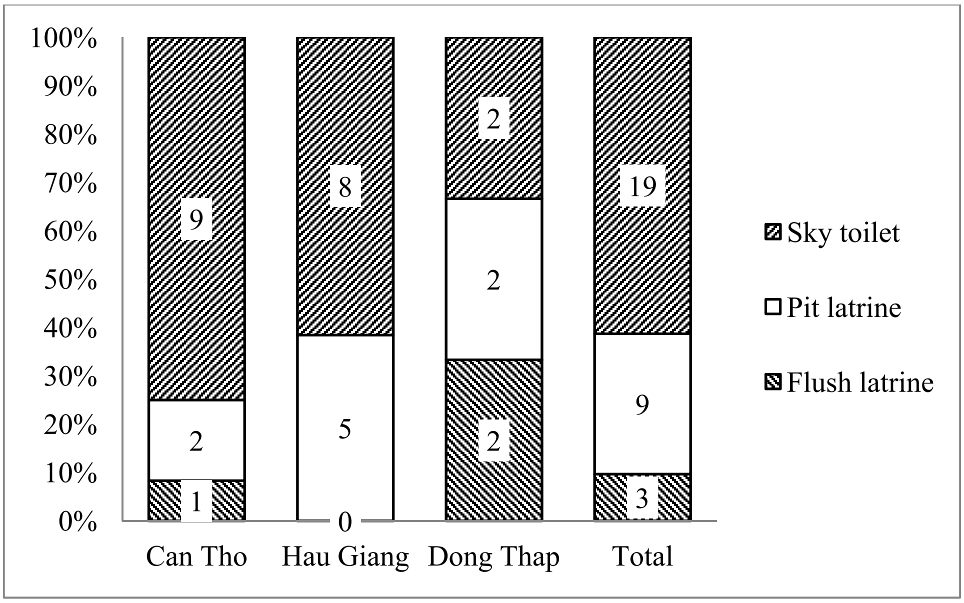


Fig 3.18 Types of latrine at households

3.5.2 The farmers' awareness on biogas plant application

According to this survey, despite living at the same area with the biogas user households, only 48% of the non-biogas user households were aware of biogas technology, 29% knew a little about and 23% had no knowledge on biogas technology. It seems strange since only 25% of the non-biogas user households in Can Tho said "yes" to the question if they have knowledge on biogas technology while 54% of the non-biogas user households in Hau

Giang said "yes" to the same question. The farmers with low educational level in the rural areas got more biogas knowledge than the farmers living in the suburban areas did.

Concerning to question of how farmers got the biogas information, there are 39% of the non-biogas plant farmers were got the biogas knowledge from their neighbors, 23% from the local authorities, 13% from the public media, 3% from biogas masons, and 22% from other sources. These sources are similar to the sources of biogas knowledge from which 29% of the biogas user households got biogas information from their neighbors and 14% from the public media. This result suggests that the biogas support project should arrange a good plan for communication information program on biogas technology.

On the reasons why the non-biogas users not install a biogas plant even they aware on biogas technology, 11% farmers did not trust on biogas plant and 29% complained of high investment cost. In addition, 50% survey farmers chose "others" as their answers that could imply to high investment cost. It could be conclude that a big barrier on application of biogas plant in this region is investment cost.

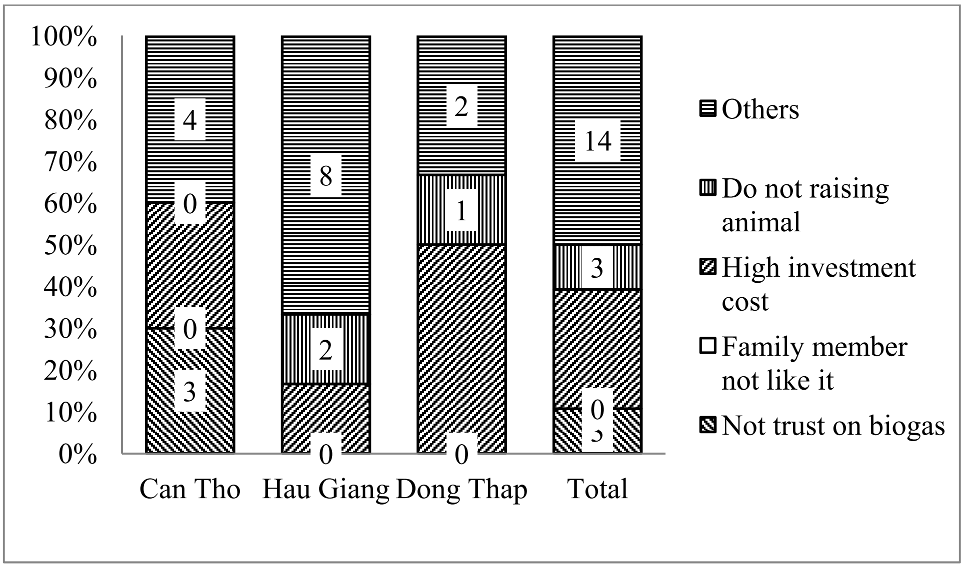


Fig 3.19 The reasons for no installation of biogas plant

Over 50% of the survey farmers wanted to build biogas plants, 18% did not decide on building biogas plants yet, and 32% did not want to build biogas plants. Most of the farmers who were not interested in biogas plant construction had no knowledge of biogas technology, but the main reason behind this answer is related to economic aspect. These farmers were classified into the group of poor living condition, so they did not think of building biogas plants due to their limited financial capacity.

Although most of the survey farmers complained about high investment cost of the biogas building, but many of them were willing to build a biogas plant if being given any supports. The survey data showed that 57% of the survey farmers preferred receiving a support of 50% of the biogas plant construction cost, 7% needed credit loan for 50% of the biogas plant construction cost. There were 36% of the farmers answered “do not know” - but it assumed that they would like to have financial support for the whole biogas plant construction cost. This assumption is made on the fact that through the interview process, even they were introduced on the interview purposes, but most of them always asked if they get any biogas construction support later on.

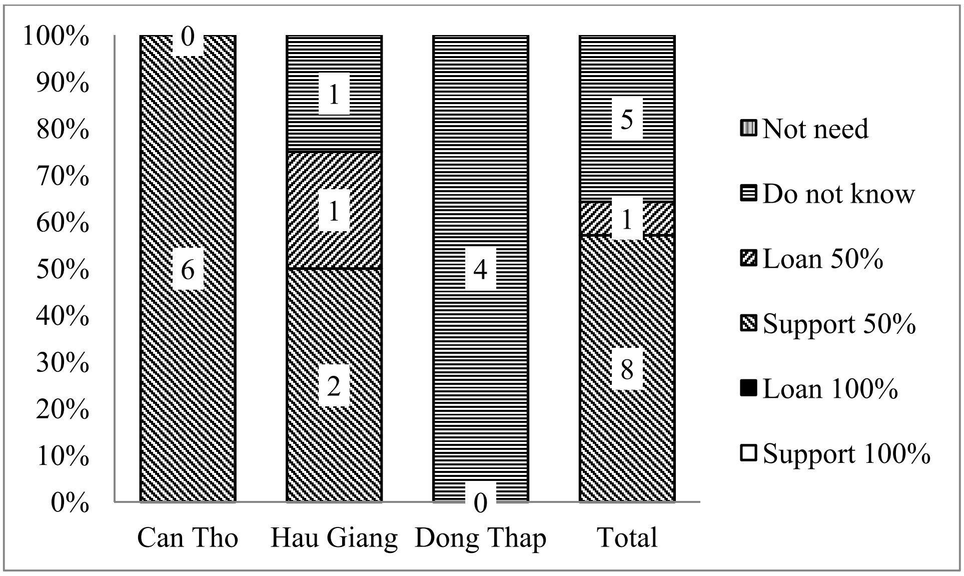


Fig 3.20 The farmers’ opinions on biogas plant construction support

On the question if farmers knew any information of biogas support programs, about half of the survey farmers said “yes” - 48%. Most of the survey farmers who wanted to build biogas plants were in the group of knowing information of biogas support programs. Unfortunately, they had no chance to get involved in any biogas support projects. Nowadays, within the SNV project, based on the project’s objectives, each households would be supported 1.2 million VND to build a KT2 biogas plant in the MD. This financial support covers about 1/5 of the investment cost of a 4 m^3 biogas plant, and this support is likely too small in case the farmers build a bigger volume plant. It is hard to meet the farmers’ desire when they prefer a financial support of 50% of investment cost.

3.5.3 Other aspects

According to the survey result, 38% of the survey households used wood and 34% used liquid petroleum gas (LPG) as the main fuel sources for their cooking. Some of households also used electricity for rice cooking. Moreover, farmer named other sources of cooking fuel such as coal (2 households), rice husk (1 household), and sawdust (1 household).

The price of LPG has been rising incredibly in the last few years. The price of one pot of 12 kg LPG was about 190,000 VND in January 2009, but it grew up to 380,000 VND in May 2011. In average, each household consumes one pot of 12 kg LPG for cooking within 2 to 3 months. To supply fuel enough for their daily cooking demand, in addition to using

LPG for cooking, the farmers still maintain the wood-stoves. Concerning to wood for cooking, farmers collect fresh wood from trees in their gardens, split them into small pieces and dry them under sunshine. The dried wood then is stored in a lean-to for cooking. Even though the farmers do not pay for wood, they need to spend time on collecting and drying the wood. It is easy to do these works in dry seasons but hard in rainy seasons. The fresh wood needs more sunshine to be dry but the sunshine is limited in rainy season.

There was no chance to record the farmers' expenses on wood because most of the farmers collected wood from their gardens. If assumed that the farmers use only LPG for cooking in rainy seasons, without labor cost on collecting wood for cooking, the farmers need at least two pots of 12 kg LPG for cooking per year. The minimum annual expense that a farmer has to pay for cooking fuel is around 800,000 VND.

3.5.4 A summary of the interview results of the non-biogas users

- Almost of farmers had livestock but pig is most raising animal. In general, each household raising from 4 to 10 pig herds but more than 60% of pig wastes were direct discharge into water open sources.
- The people in the rural areas could get more knowledge on the biogas technology than the people living in the suburban areas could. This point indicated that people living in the rural areas more open and pleasure to sharing their information to the neighbors.
- Most of the non-biogas user households were awareness the biogas information from their neighbors or local authorities. Moreover, nearly half of them knew on the biogas support programs but they were not involved as project's beneficiaries.
- Only 11% of the survey farmers did not trust into the biogas plant but more than half of them expected to get at least 50% fund support to build a biogas plant that clearly showed that the investment cost is big barrier of farmers on biogas construction.
- It needs to consider micro-credit projects to support poor farmers in the MD invest for a biogas plant, especially from the government that helps improve the community health care and ensure for fuel requirements from rural areas.

3.6 BIOGAS MASONS SURVEY RESULTS

3.6.1 General information

Most of the survey biogas masons are the senior masons of the biogas mason groups. There were 5/9 of the masons formerly freelance masons, and when a biogas project implemented at their living places, the project trained them so that they can build biogas plants and worked for the project as biogas plant masons. After the completion of the project, they continued building biogas plants when required by some households. Some of the survey masons have ten-year experience of biogas construction, while some have worked in biogas construction for two years.

There were 7/9 survey masons own biogas plants at their households and most of them have built their plants by themselves. Two masons have no biogas plants because they do not raise pigs at their households. Owning to their practical experience of building and using the biogas plants, these masons could become good propagandists for biogas plant promotion in the region.

By the survey record, 8/9 of the survey masons attended the biogas training courses. In which 5/5 of the masons in Hau Giang (56% of the total number of the survey masons) have been trained by the VIE020 project, and 3/4 of the masons in Can Tho (33% of the total number of the survey masons) have been trained by the project SNV. At some biogas mason groups, all members (including assistant masons) attended the biogas training courses while at some other groups only the senior masons (not including the assistant ones) have been trained.

Each biogas mason group normally consists of two or three persons, and most of them are male due to hard construction works. Even some biogas masons are freelancers (without joining any mason groups); when building a biogas plant, he will employ some assistants at the local areas to help him undertake his construction works.

The biogas masons informed that after the completion of the project, they have built the biogas plants when employed, but not only for households as defined by the project. However, it is not easy for the masons to find out the households who want to build biogas plants. Only one mason could find out the households want to build the biogas plant by self-introduction. Most of the biogas masons (6/9) could maintain the biogas construction job thanks to the recommendation of their former customers. This result showed the figure on supply is failing to keep up with demand.

Among the 9 biogas masons, only 3 masons worked regularly on the biogas building, 5 masons seldom worked on biogas construction, and 1 mason stopped building biogas plants. The mason who informed that he did not build biogas plants anymore complained of the low salary in comparison with the other job income. Meanwhile 8/9 of the biogas masons agreed that their biogas construction income is higher than other construction incomes. A limited number of biogas plant constructions do not reflect a low demand on biogas constructions from farmers in the areas. The demand on biogas construction is still high but farmers face some problems of biogas constructions that constraint their biogas plant construction possibility such as limited financial capacity and lack of information on biogas masons.

For the biogas plant building, 6/9 of the masons informed that they constructed the biogas plants mostly at dry seasons, while the other three masons said that they constructed biogas plants during the whole year. In fact, to build a biogas plant in the rainy season could lead to the extension of the construction time and affect the construction quality.

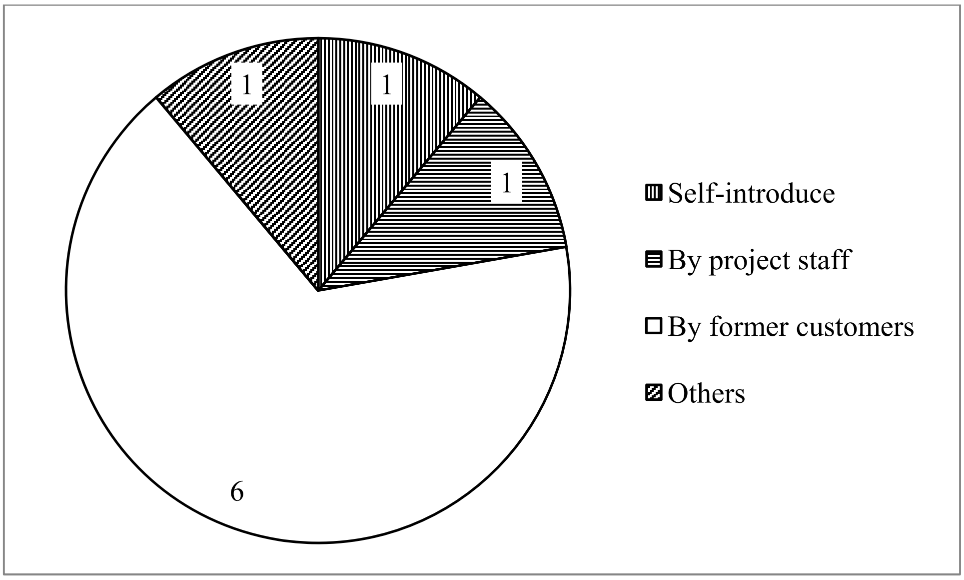


Fig 3.21 How to find out the household want to build the biogas plant

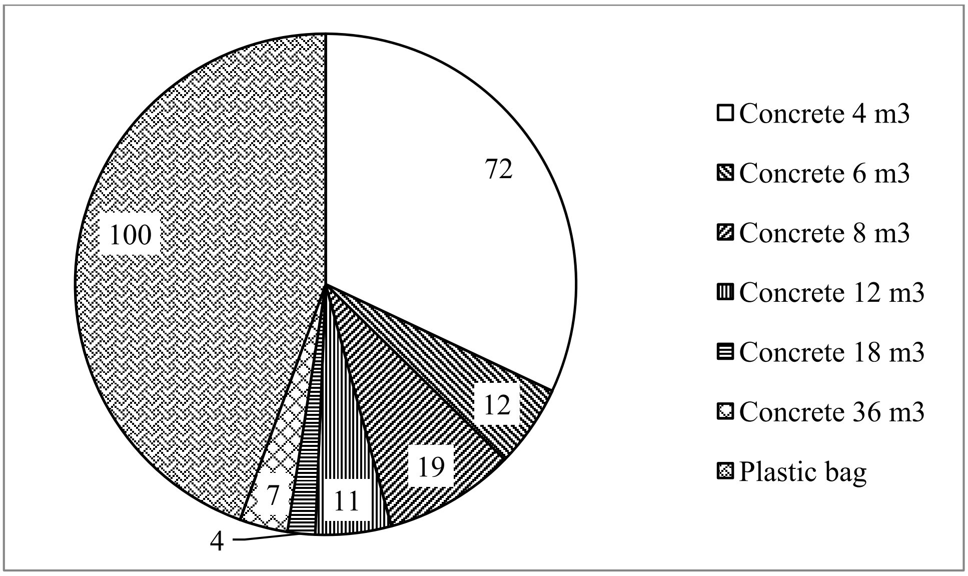


Fig 3.22 Types of the constructed biogas plants

Looking at the types of the biogas plants the masons have already built, there were 44% of the plants were PE digesters and 56% were the concrete models. Among the concrete models, 58% are up to 4 m³ plants, 10% are from 4 to 6 m³ plants, 15% are from 6 to 8 m³ plants, 9% are from 8 to 12 m³ plants, 3% are from 12 to 18 m³ plants, 6% are from 18 to 36 m³ plants. Based on the data, it clearly that the 4 m³ biogas plant model were mostly popular in the MD due to livestock raising at household scale of 4 to 10 pig herds.

3.6.2 Biogas construction works

In this section, some information related to the biogas construction works was described. Regarding the choice of the location of biogas plant, most of the survey biogas masons gave their customers their suggestion due to their experiments (78%), but the customers also gave their voice (22%). In case get a biogas plant construction from support project, farmers could not decide on the construction place of his plant, but the project staff and/or the biogas masons will make the decision. Only the households who do not get involved in any projects can make their decision on the location of their biogas plants.

There was 78% of the biogas plants have been built with the capacity based on the quantity of input materials. Only 11% of the biogas plants have been built with the biogas plant capacity due to the biogas plant owners' financial capacity. After attended to the training courses, the biogas masons know how to calculate the volume of biogas plants by basing on number of pig herds raised at each household. It is important to choose a proper plant volume based on input capacity. In fact, being decreased the plant volume to fit the household's budget, the biogas plant is vulnerable to some negative problems such as less gas, polluted effluent, etc.

When build a biogas plant, the materials play a key role on construction quality. For the biogas plants construction, there were standards on construction materials that the masons have to follow [_____, 2002]. Especially in case of fixed-dome biogas plants, the masons must strictly follow standards of construction materials to ensure airtight status. This survey result showed that 7/9 biogas masons decided on the construction materials.

For the project SNV, the project would support a biogas plant construction financially and that type of plant should strictly follow the design. This requirement ensures the biogas plant quality, but from this survey result, there was only 5/9 of the biogas masons have built the biogas plants of the project according to the design, the rest of the masons did not follow the design strictly while constructing the biogas plants of the project. The biogas masons also mentioned some problems happening during the biogas construction process, but most of them could treat the problems by themselves.

For the biogas plants constructed within the projects, the biogas masons had to sign a warranty with all household heads. In contrast, for the biogas plants not constructed by the projects, few the biogas masons offered a warranty to the biogas owners. Only for the PE digesters, the biogas masons could not signed any warranty due to sensitive situation of this biogas plant type.

3.6.3 Biogas O&M works

From this survey, the lifetime and operation of the biogas plants seem in good condition because few of the biogas masons have been required to fix biogas plant problems. Only

5/9 of the biogas masons faced to biogas plant failure, but in most of the cases, the failure happened at PE parts and outer gas devices. The PE bio-plants with digesters and gas-holder parts are made from PE, and the EQ1 and EQ2 plant models consist of PE gas-holders. By the experience of the biogas masons, the problems mostly came from the PE parts (100% of failure case).

Even the farmers had a good biogas plant of airtight and water-tight but, after construction time, the well-operation plays a key role in the efficiency of waste treatment and biogas production. To keep the biogas plant in a good operation, the biogas masons and/or the project staff should give the biogas owners instructions on biogas plant operation. How did the survey biogas masons advise their customers to maintain the biogas plants in the survey areas? This survey results showed that only 2 masons reminded the farmers of maintaining the quantity of livestock after they own the biogas plants. Because most of the biogas plant volume has been defined based on the input capacity, the produced biogas will decrease in case the farmers reduce the pig herds. In contrast, if they raise more pigs, the effluent becomes dirtier and even leads to less biogas. The farmers should be aware of this matter so that they can keep their livestock number in stability to remain the produced biogas.

Another matter is related to the biogas plant feeding. The survey showed that less than half of the survey biogas masons (4/9) have guided the farmers on biogas plant feeding. The farmers who had no knowledge on this matter could operate their biogas plants improperly. In respect of the popular biogas plant models in the MD, there are limitation in hydraulic retention time designed from 17 to 30 days, and the mixing ratio of pig manure and water from 1:1 to 1:2 depending on each model. At present, the farmer in the MD mostly use waterspout with electricity motor to clean their pigpens, so they cannot control water volume they apply into their biogas plants per day. A survey on water applied for pigpen cleaning at 52 biogas user households showed that the survey farmers applied too much water into their biogas plants (the result not shown). The overload of water could cause a reduction in biogas production volume as well as dirty effluent in the digester process.

It is required to have periodical checks on biogas plant and all devices to ensure the biogas plant operation in good condition. In this survey, 56% of the survey masons had given the farmers some tips on maintaining their biogas plants, 60% asked the farmers to check if the gas decreases, 20% recommended the farmers to remove scum and slurry in their plants, and 20% reminded the farmers to maintain water layer on the top of tank for airtight (at the fixed-dome model). For biogas treatment method, only 2 biogas masons instructed the farmers how to do the biogas treatment method but only one household in the Hau Giang site applied the gas treatment method was recorded. When the biogas masons were asked why the farmers had not done the recommended gas treatment methods, they said that the farmers were afraid of using some complicated devices. Because the farmers applied biogas only for cooking, they did not take a due care on biogas treatment methods.

The application of bio-slurry to farming cultivation is highly encouraged in the region. A biogas mason should inform farmers of the benefits of the bio-slurry from biogas plants so that farmers will apply bio-slurry to their cultivation. Among the biogas masons, one did not guide the farmers on bio-slurry application. For the rest, mainly they introduced the application of bio-slurry as fertilizer and/or adding to fishpond to the farmers.

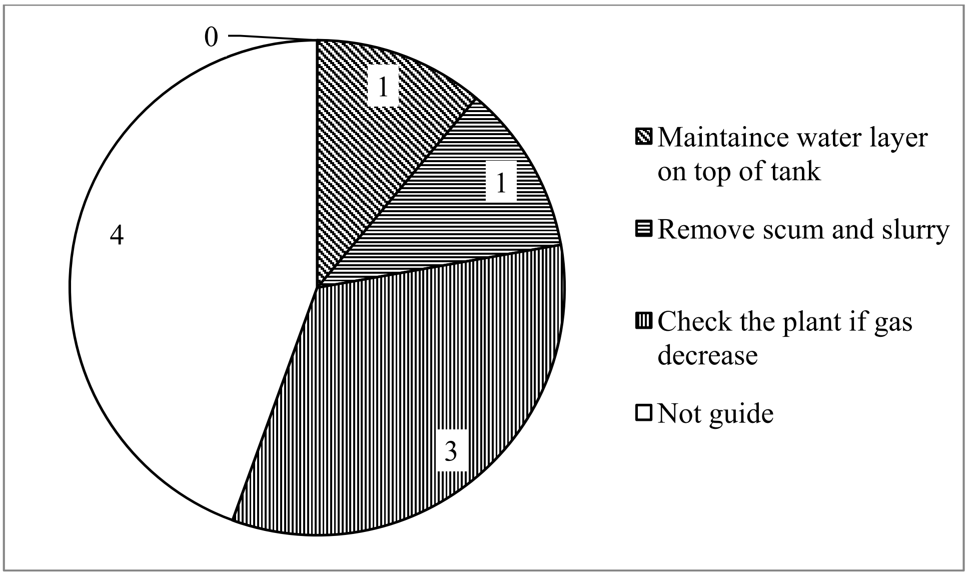


Fig 3.23 Guiding on digester maintenance

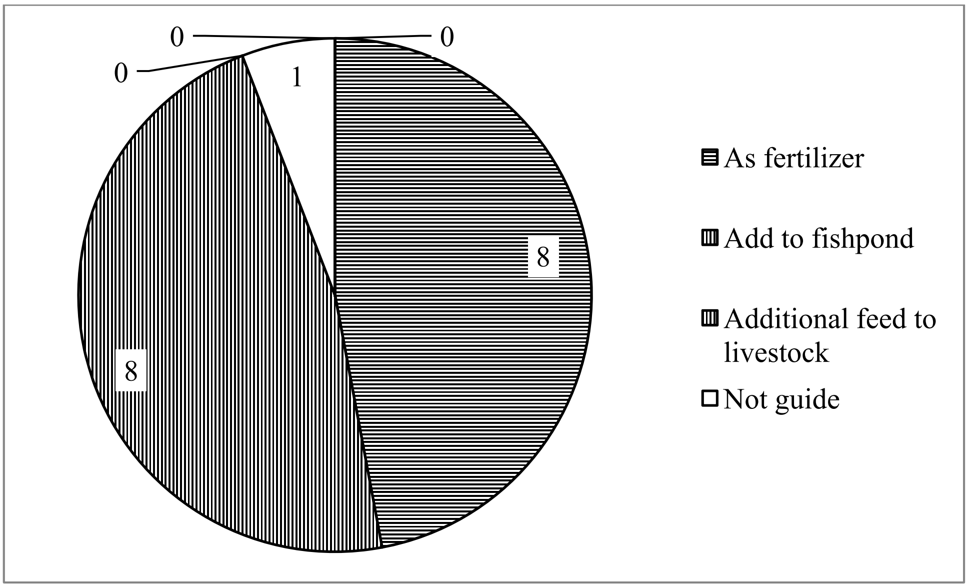


Fig 3.24 Guiding on apply the bio-slurry

3.6.4 Other comments from the biogas masons

Most of the biogas masons got satisfaction from their clients. The biogas masons followed the warranty well, and said that even when a given plant is no longer under the warranty, they will help their clients to fix any failures. Some of reasons that the farmers satisfied with their works are the biogas plants were in good operation (43%), completing the construction in time (14%), no extra payment (14%).

Based on the existing biogas situation in the region, 7/9 of the biogas masons anticipated that the number of biogas plants would increase significantly in the MD in the future.

3.6.5 A summary of the interview results of the biogas masons

- Some of the survey biogas masons have not strictly followed the design of the biogas plants while building a biogas plant.
- The farmers have not applied gas treatment methods because they used biogas mainly for cooking.
- The farmers have supplied too much water into the biogas plants, causing a decrease in the efficiency of waste treatment and biogas production.
- As regards the participants of the biogas plant construction courses, project staff should choose farmers having experience on construction so that they are able to understand the training information well.

3.7 CONCLUSIONS AND RECOMMENDATIONS

In spite of having been long established in the MD, the biogas application is limited in terms of quantity and quality of the biogas plants. To evaluate the current situation of the biogas application and its potential promotion in the MD, a survey was done by interviewing the farmers and the biogas masons at the three sites of the MD, namely Can Tho, Hau Giang, and Dong Thap. In total, the survey involved 117 farmers who were divided into three groups: one group of biogas users (77 farmers), one group of non-biogas users (31 farmers), and one group of biogas masons (9 farmers).

From the survey results, there were some practical benefits of biogas plants that can be used to promote widespread biogas application in the MD:

- Biogas plants did not only directly generate income for the households but it could also solve partly the environmental pollution caused by livestock wastes and simultaneously provide the biogas for living activities, and produce bio-slurry applicable to organic cultivation in the region.
- The average income of the biogas user households was higher than that of the non-biogas user households at all of the three survey sites, showing the economic positive effects from biogas application.
- The farmers were found to be interested in biogas plants mostly due to its hygienic and economic benefits. Nowadays, many people in the MD are more and more aware of the

pollution of water sources in the region. Applying biogas plants on livestock waste treatment could minimize the pollution situation. The economic benefits of biogas plants include saving expense on cooking fuel, application of the bio-slurry as a complement fertilizer, etc.

- At present, the husbandry master plan requires the livestock farms (particularly the large scale and medium scale ones) have to build a livestock waste treatment system (DLP, 2007). This policy opens more opportunities to apply biogas as a treatment technique for livestock waste treatment in the MD.
- Biogas plants not only apply as a livestock treatment method but also a source of fuel supply. Biogas plants are promising sources for lighting, especially in case of rural Vietnam where shortage of electricity is still a concern.

However, the biogas plant promotion in the MD has faced some outstanding challenges:

- In recent years, the construction material prices and the labor cost are dramatically increasing, causing a rise in the biogas construction cost. Nevertheless, this survey showed that the farmers have been aware of the benefits of the biogas plants to improve their living conditions, so many of local farmers are willing to consider building biogas plants if there is any support available.
- Both the biogas users and non-biogas users agreed that the investment cost is the largest barrier when they make the decision on the biogas plant construction. The second thing is the variation on the livestock market that causes decrease in livestock quantity. Development and using of biogas plants depend much on the livestock price. In case the livestock price goes down, farmers will reduce the scale of raising livestock or even stop raising livestock.
- The biogas equipment market (biogas stove, biogas rice-cooker, hydro sulfur filter, biogas lighter, etc.) is not well-developed in the MD. Besides that, some raising problems concern the development of biogas equipment. There were many groups of masons involved in biogas plant construction and they tried to improve the biogas technology. An example is the improvement of EQ2 biogas plant from TG-BP model, in which a crank handle was added to the EQ2 plant to mix the biomass substrate. However, the crank handles are highly costly and hardly available at local markets.
- Most of biogas construction masons are freelance masons, so after-built services are not wide and convenient. These masons are limited on biogas technology knowledge and have no opportunity to advertise their work.
- There is inadequate management from government on livestock waste management. Actually, up to now there is no issuance of government standards on livestock waste discharge and farmers just simply wash out all livestock waste into open water sources.

Moreover, the dissemination of biogas technology knowledge and biogas benefits on the media is limited, thereby negatively affecting the widespread biogas application in the region.

Recommendations

- Most of the biogas user households and some of the non-biogas user households acknowledged the advantages of biogas for cooking but they did not know the environment aspect of the biogas plants. It is essential to pay more attention to improve communication channels to raise the farmers' awareness on the benefits of the biogas plants to the environment protection.
- It is necessary for the biogas masons to improve their construction skills and responsibility in further works by improving the building technique and quality, the better behavior in serving and guaranteeing.
- It could be more effective if the government pays more attention to biogas dissemination program via the media so that farmers in the rural areas could approach the biogas technology.
- The competence authorities should consider issuance of standards on livestock waste discharge in order to address the problem of freely discharging wastes into open sources.

CHAPTER 4. ANAEROBIC CO-DIGESTION OF PIG MANURE WITH WATER HYACINTH AND SPENT MUSHROOM COMPOST

4.1 RESULTS ON FEEDING MATERIALS

As regards anaerobic processes, the degradation of organic matters was measured based on ODM value of input material. The mixing ratio of input materials in this study was calculated according to their ODM values. Eder and Schulz (2007) suggested that the optimal input should be 1 ÷ 4 kg ODM $day^{-1}.m^{-3}$ for an anaerobic digester. Based on this suggestion, the input discharge in the experiments was chosen to be 1.25 g ODM $day^{-1}.L^{-1}$. Consequently, 630 g and 665 g (based on ODM values) was fed to the PM+WH and PM+SMC treatments, respectively.

Table 4.1 The mixing ratios on dry weight basis

Treatments \ Co-digestions	PM+WH treatments			PM+SMC treatments		
	PM	***WH***	***Total***	***PM***	***SMC***	***Total***
Batch treatments (g/digester)						
100%PM+ 0%WH/SMC	2254	0	2254	2380	0	2380
75%PM + 25%WH/SMC	1691	256	1947	1785	268	2053
50%PM + 50%WH/SMC	1127	512	1639	1190	535	1725
25%PM + 75%WH/SMC	564	769	1333	595	803	1398
0%PM + 100%WH/SMC	0	1025	1025	0	1070	1070
Semi-continuous treatments (g/digester*day^{-1})						
75%PM + 25%WH	60.40	9.20	69.60	64.00	9.55	73.55

The relationship between the amount of carbon and nitrogen available in organic materials is represented by the carbon-to-nitrogen (C/N) ratio. Microorganism generally utilizes carbon and nitrogen in the ratio of 25/1 ÷ 32/1 [Bouallagui *et al*. 2003]. A good reason for co-digestion of PM with biomass varieties is the adjustment of the C/N ratio. Because the C/N ratio in PM is low while it is high in WH and SMC, the co-digestion of PM with WH or SMC can help adjust the C/N ratio closer to the optimum value.

In this study, the C/N ratio of the input materials ranged from 9 to 25, which is slightly different in comparison to those in the previous studies in Vietnam. The C/N of input materials can however be significantly affected by the factors such as biomass varieties, cultivation system, soil condition, applied fertilizers, etc. For an anaerobic process, with an increase in C/N ratio, the concentration of methane in the biogas decreases [Hills, 1979].

Table 4.2 The comparison of C/N ratios in the various references

No.	C/N ratio				Sources
	PM	***WH***	***SMC***	***RS***	
1	9.6	24.5	24.6	-	In this study
2	33.4	25.2	-	40.5	Nguyen (2010)
3	14.4	21.4 ÷ 23.5	-	53.2	Nguyen *et al*. (2009)
4	-	-	16.6 ÷ 29.8 *	42.4 ÷ 45.7	Luu and Nguyen (2006)
5	12.0	25.7	-	14.2	Nguyen (1989b)
6	-	18.2 ÷ 30.7	-	-	Nguyen and Phan (1989)

Note: RS: rice straw

(-): not available

(*): rice straw at 3 ÷ 4 weeks after Trichoderma fungi treating (C/N ratio from 24.12 ÷ 29.81 in dry season and 16.64 ÷ 19.25 in wet season)

4.2 RESULTS OF PM+WH BATCH TREATMENTS

4.2.1 Biogas volume

The biogas volume was collected through the aluminum bags and recorded once a day for 28 continuous days. The daily generation of biogas in relation to the various mixing ratios of PM+WH treatments are displayed in Figure 4.1.

The fluctuation in gas production was present in all the treatments during the experiment period. The gas production peaked on the days of 6^{th}, 8^{th}, 6^{th}, 6^{th} and 7^{th} in the treatment of 100%PM+0%WH (9.8 L), of 75%PM+25%WH (11.8 L), of 50%PM+50%WH (14.1 L), of 25%PM+75%WH (15 L), and of 0%PM+100%WH (15.6 L), respectively. Generally, from the 23^{rd} day of the operation onwards, no appreciable gas quantity was produced in all the treatments. In this study, the peak of gas production happened at early stage of the digestion process (in the first week) due to the addition of inoculums to the treatments; otherwise, it could take more time for the occurrence of the peak of gas production in case of fermentation without seeding [Lopes *et al*. 2004]. By seeding the treatments with the effluent taken from an activated biogas plant, the activated anaerobic microorganism had already presented in the effluent, providing energy and nutrient to the digester at an early stage of the digestion process. In a similar instance, El-Shinnawi *et al*. (1989) found that the early evolution of biogas was attributed certainly to the enriching inoculation with the partially digested cattle dung. The initial phase of anaerobic fermentation is needed for microorganism population to proliferate and thus shortens the retention time.

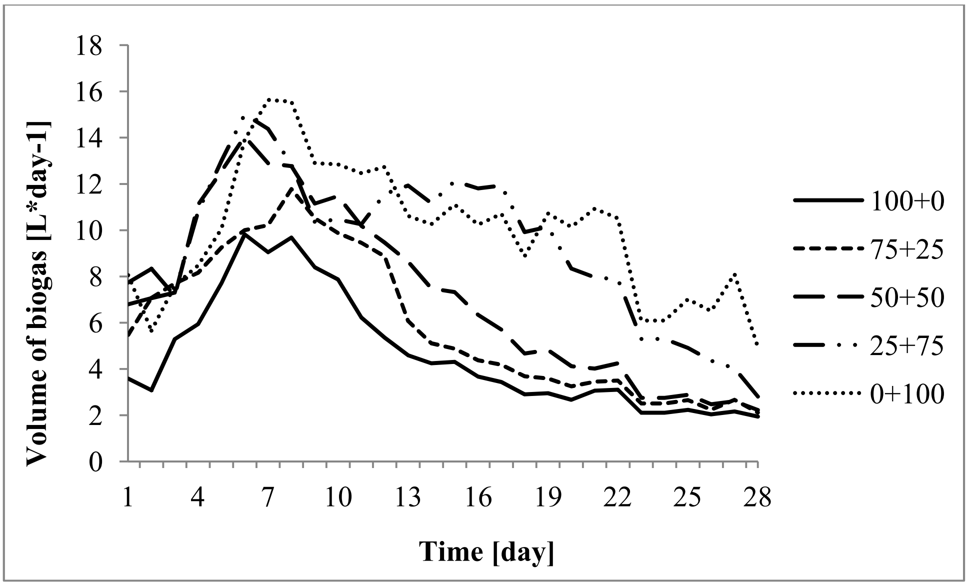


Fig 4.1 The biogas produced daily in the PM+WH treatments

In all the treatments the gas volumes in the 4th week were different from those in the other fermentation weeks. The biogas produced in the 4th week made up only 17.7%, 13.3%, 9.9%, 11% and 12.1% of the total biogas volume in the treatment of 100%PM+0%WH, of 75%PM+25%WH, of 50%PM+50%WH, of 25%PM+75%WH, and of 0%PM+100%WH, respectively. The results of the study indicated that a 28 day period is not yet the sufficient duration for the anaerobic fermentation progress. It is need more time to completely ferment the biomass content.

The cumulative volume of biogas in Figure 4.2 showed the biogas yield extracted from the treatment of 0%PM+100%WH, of 25%PM+75%WH, of 50%PM+50%WH, of 75%PM+ 25%WH, and of 100%PM+0%WH in descending order. After 28 days in operation, the 100%PM+0%WH treatment produced the lowest biogas volume while the highest biogas volume was in the 0%PM+100%WH treatment. In fact, this case occurred apparently due to the higher methane potential of water hyacinth compared to pig manure.

Within 28 operation days, more than 50% of the total produced biogas was obtained within the first 10 days of the operation of the treatments of 100%PM+0%WH, of 75%PM+ 25%WH, and of 50%PM+50%WH, within the first 13 days of the treatment of 25%PM+ 75%WH, and within the first 14 days of the treatment of 0%PM+100%WH. This figure shows that the treatment of 100%PM+0%WH took a shorter hydraulic retention time compared to the other mixture treatments and that the more percentage of WH was in the mixture, the longer the hydraulic retention time was.

In regard to the mixture of PM and WH materials, the result indicated that an increase in the biogas production was attributed to the higher percentage of WH contained in the mixed substrate. The previous study by Nguyen and Phan (1989), and Nguyen (1989b) reported a similar tendency. In fact, water hyacinth is a nutrient-enriching feedstock for methane generation [Hanisak *et al.*1980; Chynoweth *et al.* 1983]. The co-digestion of WH with PM could increase the gas production compared to the treatment of sole PM.

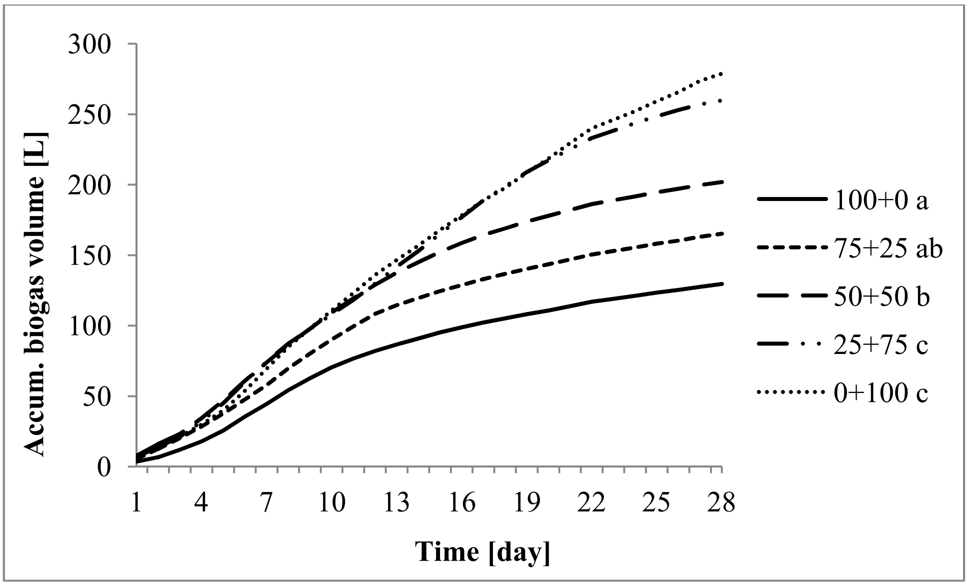


Fig 4.2 Daily accumulative biogas volume of PM+WH treatments

The differences in the gas production between the treatments are presented in Figure 4.2 in which the differences are marked by different letters a, b and c ($p \leq 0.05$ by the Duncan's Multiple Range Test). The experimental result showed that the produced biogas in the treatment fed with100%PM was significantly different from that in the treatment of PM+WH in which the mixing ratio was from 50%WH and over, and the produced biogas of the 50%PM+50%WH treatment was significantly different from that of the PM+WH treatment in which the mixing ratio was from 75%WH and over. Meanwhile, according to Nguyen and Phan (1989), there has been no significant difference between treatments with the mixing ratios of 1 PM + 1 WH, 1 PM + 2 WH, and 1 PM + 3 WH. The mixing of their study have been implemented based on DM value of input materials, but the mixing ratios in this study were based on ODM values, which is acknowledged to be more accurate.

Obviously, the difference in pH and alkalinity values on the treatments caused by the variations of the mixing ratio of PM and WH influenced the gas production. According to Gerardi (2003), the optimum pH value for biogas production ranges 6.6 ÷ 7.6. In this study, it was observed that almost the pH values of the substrate prior to the testing were within this optimum range for biogas production, except the pH value of the treatment of 0%PM+100%WH reached to 6.4. After the fermentation process, the pH values were observed to increase slightly, which is consistent to the finding reported by Shoeb and Singh (2000). The pH values after the experiment were observed to be from 7.3 to 7.6. A slight increase in the pH after the anaerobic process could be attributed to the fact that organic nitrogen was readily reduced to ammonium ion.

In addition, the results revealed that prior to the experiment the treatments in which the percentage of WH was higher would contain the lower pH values. But after the experiment, the pH values were recorded higher in the treatments with higher percentage of WH. This result indicated that the recovery capacity of pH value was stronger in the treatments with the higher mixing ratio of WH.

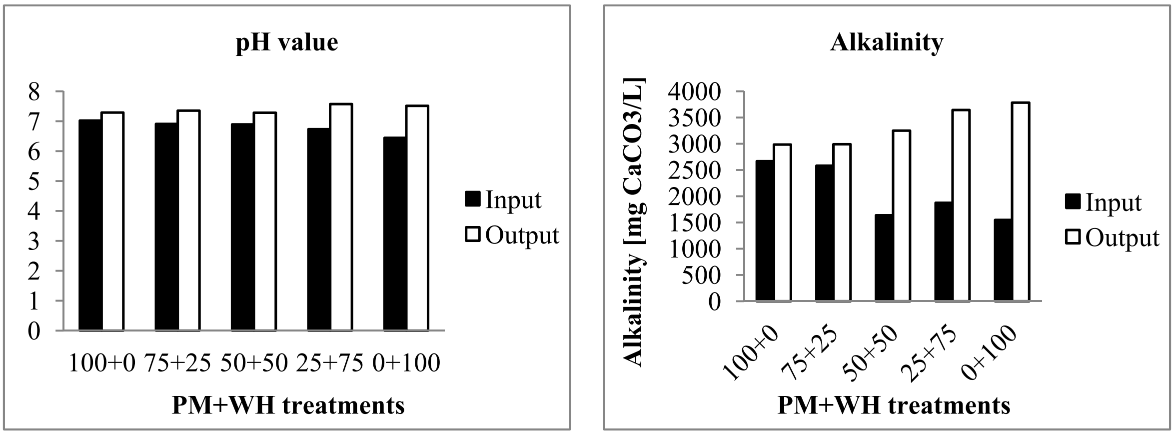


Fig 4.3 Control parameters of PM+WH treatments - pH (left) and alkalinity (right)

Sufficient alkalinity is essential for proper pH control. Alkalinity serves as a buffer that prevents rapid changes in pH. The stability of digester is enhanced by a high alkalinity concentration of optimum value 1500 ÷ 3000 mg $CaCO_3$/L [Gerardi, 2003]. Before the fermentation, the lower alkalinity values were recorded in the treatments with higher percentage of WH. On the contrary, the alkalinity values increased due to an increase in the mixing ratio of WH in the treatments. In the comparison of the alkalinity values before and after the experiment, the alkalinity values largely changed in the treatments with higher percentage of WH. The alkalinity value increased from 111% in the treatment of 100%PM+0%WH to 244% in the treatment of 0%PM+100%WH.

4.2.2 Biogas composition and specific biogas yield

The biogas composition was measured according to GA94 gas analyzer. Accordingly, at least 1 litter of biogas is required for the measurement. At the initial phase of the fermentation, the biogas production was relatively low, and the biogas was stored in the aluminum bags and recorded once a week. The analytical results of the composition of the biogas generated in all the PM+WH treatments are displayed in Figure 4.4.

The major components of biogas are methane and carbon dioxide. This study concentrated on the value of methane content, and this value in the collected biogas tended to increase in most of treatments. At the initial phase of the experiment, it could be more percentage of impurities presented in the generated biogas which caused lower methane content (only 45.8 ÷ 50.6%) within the first week.

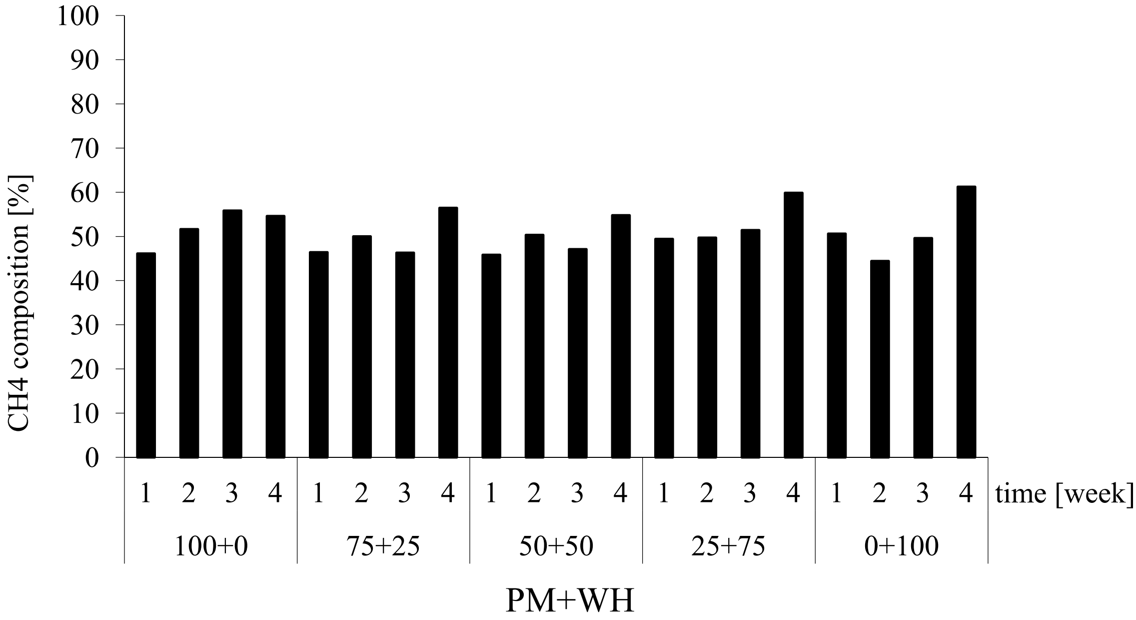


Fig 4.4 Biogas composition of PM+WH treatments

In the comparison between the treatments, the treatment with a larger percentage of WH generated not only higher gas production but also higher methane content in the gas. The methane content reached at 60% during the last weeks of the experiment for the treatments of 0%PM+100%WH and of 25%PM+75%WH. In this connection, Dirarand El-Amin (1988) reported that the methane content in their study was up to 76% in the biogas and the percentage of methane in the digesters declined in the later stage. The results in this study are in line with their observation.

The calculations of biogas yield for each treatment were based on weekly biogas production and fermented ODM value. The fermented ODM values of PM+WH treatments are show in Table 4.3. The results showed that higher biogas yield was presented in the treatments with larger percentage of WH in the mixing ratio. Compared to the treatment of 100%PM+0%WH, the biogas yield increased by 131%, 160%, 201% and 235% in the treatments of 75%PM+25%WH, of 50%PM+50%WH, of 25%PM+75%WH, and of 0%PM+100%WH, respectively.

Table 4.3 The fermented ODM from treatments of PM+WH

%PM+%WH	ODM input (g)	ODM output (g)	%ODM fermented
100+0	630.00	279.54	44.37
75+25	630.00	293.84	46.64
50+50	630.00	294.44	46.74
25+75	630.00	290.39	46.09
0+100	630.00	310.64	49.31

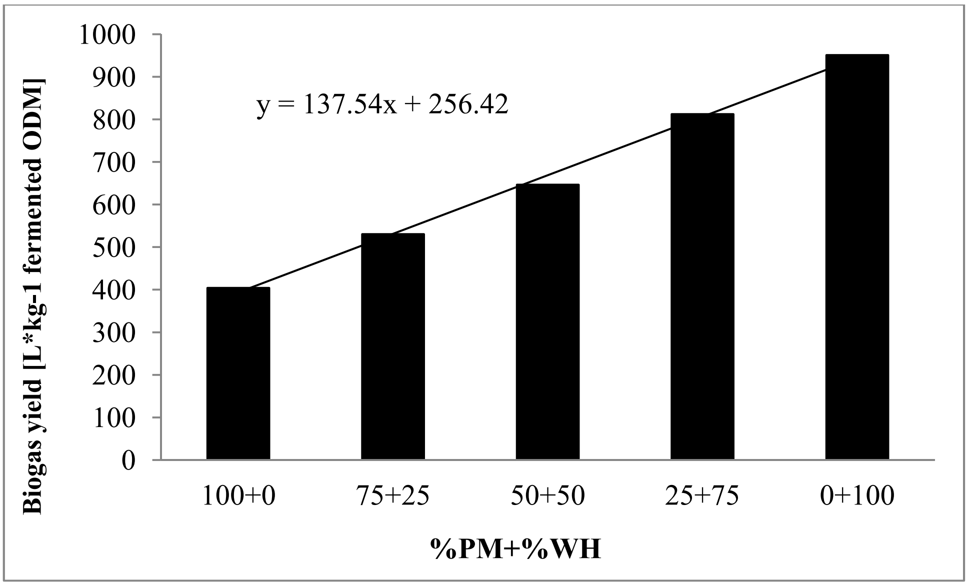


Fig 4.5 Specific biogas yield of PM+WH treatments

Besides, the relationship between the biogas yield and the percentage of WH contained in the substrate showed a linear curve fit represented by equation (1) with a goodness of fit equal to 0.9964.

$$y = 137.54x + 256.42 \qquad (1)$$

where x: percentage of WH in mixing substrates

y: biogas yield (L/kg fermented ODM)

From this equation, it is estimate when replace 25% of PM by 25% of WH in the co-input materials, the average biogas production increasing about 138 L per kg fermented ODM of the input material.

4.3 RESULTS OF PM+SMC BATCH TREATMENTS

4.3.1 Biogas volume

The result of the daily generation of biogas with a variety of mixing ratios of PM+SMC treatments is presented in Figure 4.6. The results showed that the biogas volume of the treatments reached maximum values around at the end of the 1st week (treatment 0+100 on the 7th day and the others on the 6th day). In the 2nd week, the peak value of biogas volume fell down and then slightly declined until the end of the testing period. Up to the 4th week, the produced biogas only accounted for 12.2%, 13.2%, 15.9%, 19.4% and 26.3% of the total biogas volume in the treatments of 100%PM+0%SMC, of 75%PM+25%SMC, of 50%PM+50%SMC, of 25%PM+75%SMC, and of 0%PM+100%SMC, respectively. These results showed that four-week operation is insufficiently long to ferment the substrate contained in SMC.

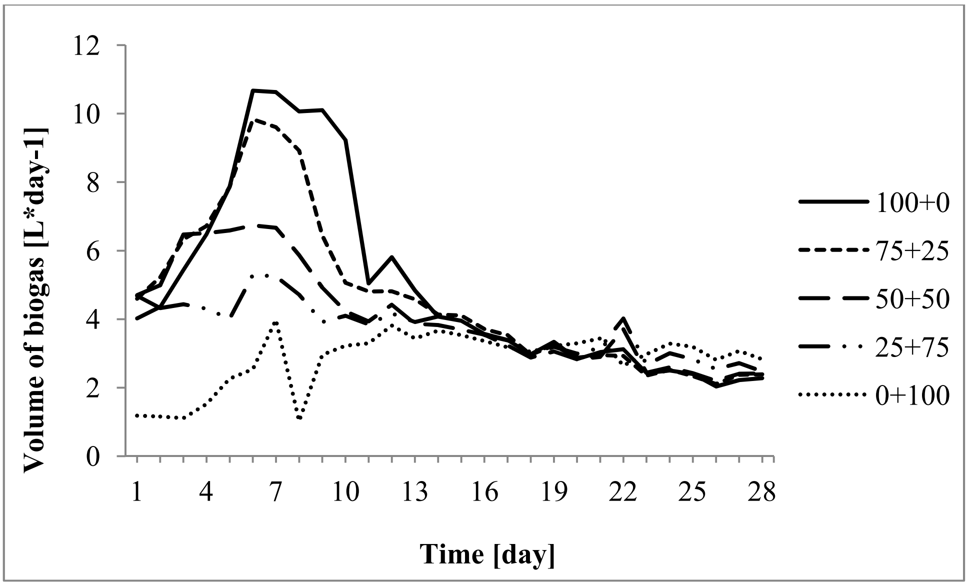


Fig 4.6 Daily biogas volume of PM+SMC treatments

The higher biogas production recorded in the last experimental period of the treatments with higher SMC content was possibly caused by high lignin content remaining in SMC. The study on methane production from rice straw by Lei *et al*. (2010) showed that the first peak of gas production happened after 20 ÷ 30 days of operation, and the second peak presented after 60 ÷ 80 days, but the second peak were always greater than the first peak. Because the fermentation time in this study lasted only 35 days, only PM and part of SMC were decomposed. As a result, only the first peak of gas production occurred in this study.

In respect with the various mixtures of SMC and PM in the substrate, the treatments with a larger percentage of SMC in the mixture generated lower biogas volume. However, the generated biogas between the treatments with SMC and the control treatment was not significantly different (except the treatment with 0%PM+100%SMC). The letters a and b in Figure 4.7 showed the difference in the total gas produced in the PM+SMC treatments. The results showed that SMC could apply as co-digestion with PM up to the mixing ratio of 25%PM+75%SMC without affecting the biogas production.

The variation on gas production between the treatments was caused by the difference in pH and alkalinity values resulted by the various mixing ratios of PM and SMC. Among undigested substrates, PM alone is the most acidic while raw SMC is the most alkaline. The mixture of PM and WH helps reach optimum pH values. But in this study, after the experiment, this tendency happened in an opposite direction, the SMC substrate was the most acidic while the PM substrate was the most alkaline. It was observed that the SMC was high lignin content that exhibited a multi-stage gas production pattern. In fact, after the peak gas production in the PM+SMC treatments, there were other small "peak" values (on the 12^{th}, 22^{nd} and 27^{th} day). It is believed that there would be re-fermentation cycle to occur in anaerobic digestion in order to complete the gasification of SMC.

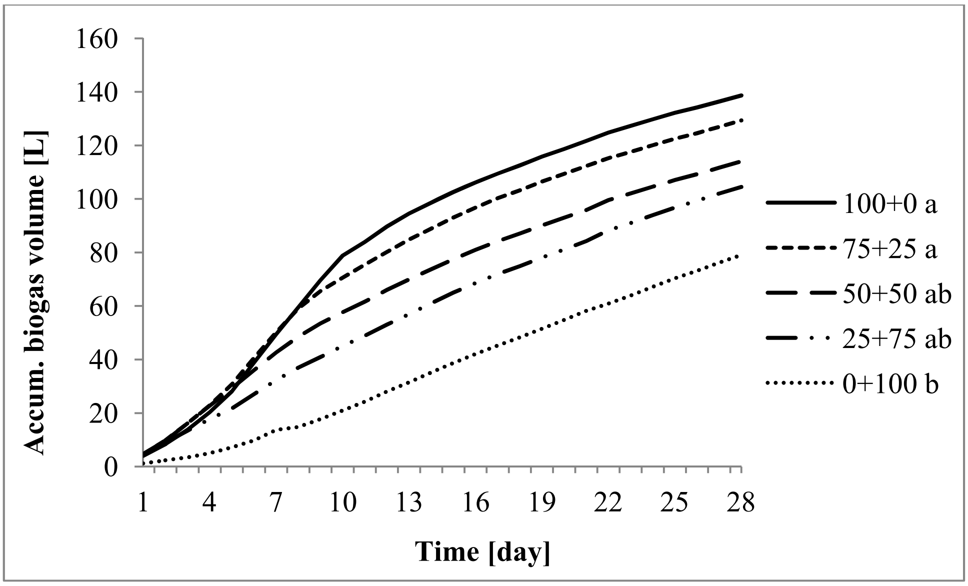
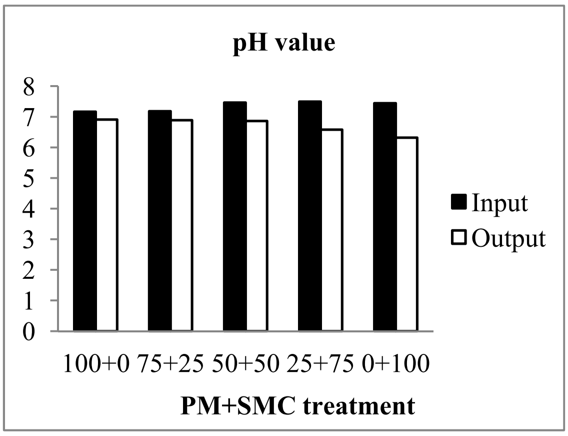


Fig 4.7 Accumulative biogas volume of PM+SMC treatments

Before the fermentation, the alkalinity value of the treatments decreased due to higher percentage of SMC in the mixture. The alkalinity is the result of the release of amino groups (-NH_2) and production of ammonia (NH_3) as the proteinaceous wastes are degraded [Gerardi, 2003]. By that fact, the treatments with high percentage of SMC could not remain the optimum alkalinity.

After the experiment, the alkalinity of the treatments tended to increase more than that of the input substrate (except the treatment of 100%PM+0%SMC). The alkalinity variation was the greatest in the treatment of 0%PM+100%SMC. The output alkalinity from the treatments with SMC content was volatile but this tendency was incomprehensible.



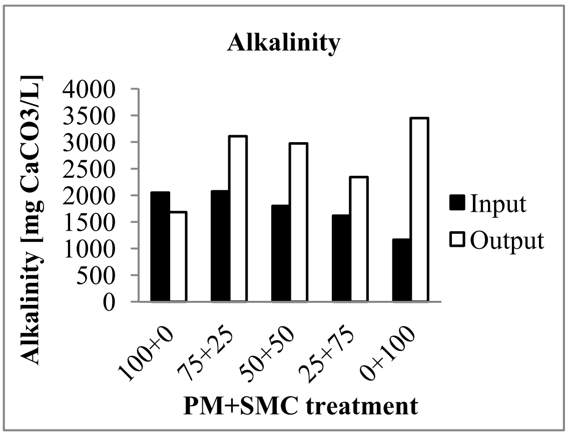


Fig 4.8 Control parameters of PM+SMC treatments - pH (left) and alkalinity (right)

4.3.2 Biogas composition and the specific biogas yield

Figure 4.9 shows the biogas composition obtained when the different mixtures of PM and SMC were used as substrates. The methane content was not much different by the mixing ratios of PM and SMC in the treatments (48.6 ÷ 55.7%), but there was a slight decrease in the percentage of methane in the treatments with the smaller percentage of SMC compared to the treatments with the larger percentage of SMC.

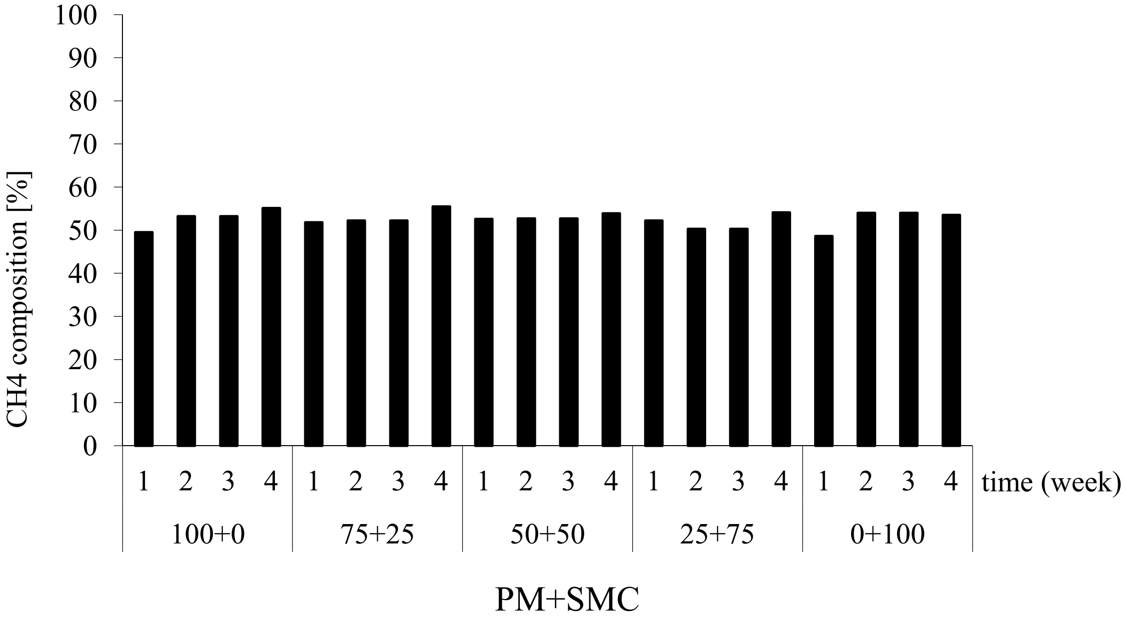


Fig 4.9 Biogas composition of PM+SMC treatments

In all the treatments, the methane content increased gradually. The maximum percentage of methane in the treatments was found in the 4th week. In this connection, Lei *et al*. (2010) reported that the methane content from rice straw anaerobic digestion could be greater than 50% after 18 ÷ 23 operation days, and these values remained between 60 ÷ 80% from the 30th day onward.

Calculation on biogas yield for each treatment was based on weekly biogas production and fermented ODM value. The results showed that higher biogas yield was present in the treatments with lower percentage of SMC in the mixture ratio. Compared to the control treatment, the biogas yield of the treatments of 75%PM+25%SMC, of 50%PM+50%SMC, of 25%PM+75%SMC and of 0%PM+100%SMC only got 84%, 76%, 69%, and 53%, respectively.

Table 4.4 The fermented ODM from treatments of PM+SMC

%PM+%SMC	ODM input (g)	ODM output (g)	%ODM fermented
100+0	665.00	317.81	47.79
75+25	665.00	287.74	43.27
50+50	665.00	298.99	44.96
25+75	665.00	297.25	44.70
0+100	665.00	282.05	42.41

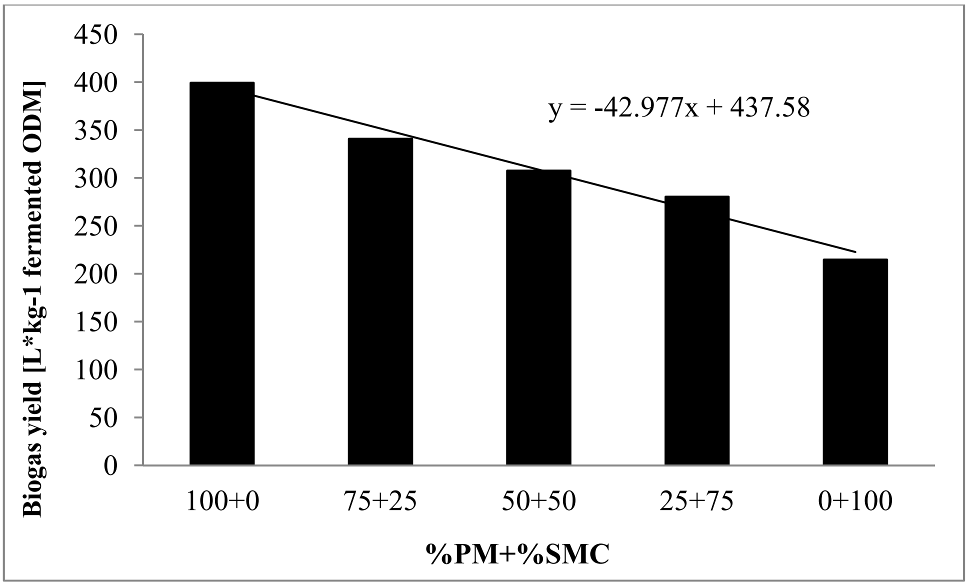


Fig 4.10 Specific biogas yield of PM+SMC treatments

Hills and Roberts (1981) reported there was an improvement in gas generation when dairy manure and rice straw were mixed to obtain a C/N ratio of 25. In this study, the C/N value was lower than the recommended value (from 9.6 ÷ 24.6). Together with the shorter time of fermentation and lose of nutrient from input materials, the lower C/N ratio resulted in low gas production in these treatments compared to the result of previous research.

In addition, the relationship between the biogas yield and the percentage of SMC inside the co-digestion showed a linear curve fit represented by equation (2) with a goodness of fit equal to 0.978.

$$y = -42.977x + 437.58 \qquad (2)$$

where x: percentage of SMC in mixing substrate

y: biogas yield (L/kg fermented ODM)

By this linear equation, it is estimate when replace 25% of PM by 25% of SMC in the co-input material, the average biogas production decreasing about 43 L per kg fermented ODM of the input material.

4.4 RESULTS OF SEMI-CONTINUOUS TREATMENTS

4.4.1 Biogas volume

For the semi-continuous treatments, because little gas was generated in the first week of the experiment, gas recording in the first week was skipped but only started to record the gas production from the 8th day up to the 90th day. The daily gas production of PM+WH and PM+SMC semi-continuous treatments was illustrated in Figure 4.11 and Figure 4.12, respectively. The daily gas production from both of the treatments was volatile and reached 3.2 ÷ 7.4 L and 2.0 ÷ 6.1 L in the treatments of PM+WH and PM+SMC, respectively.

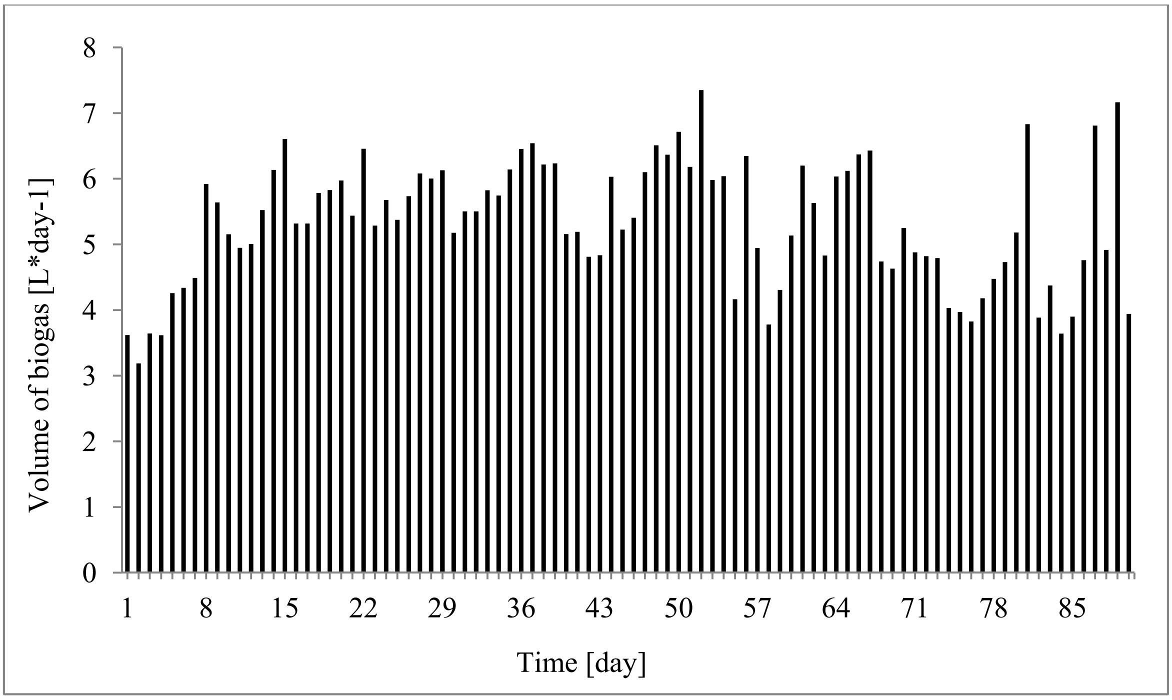


Fig 4.11 Daily biogas production of PM+WH semi-continuous treatments

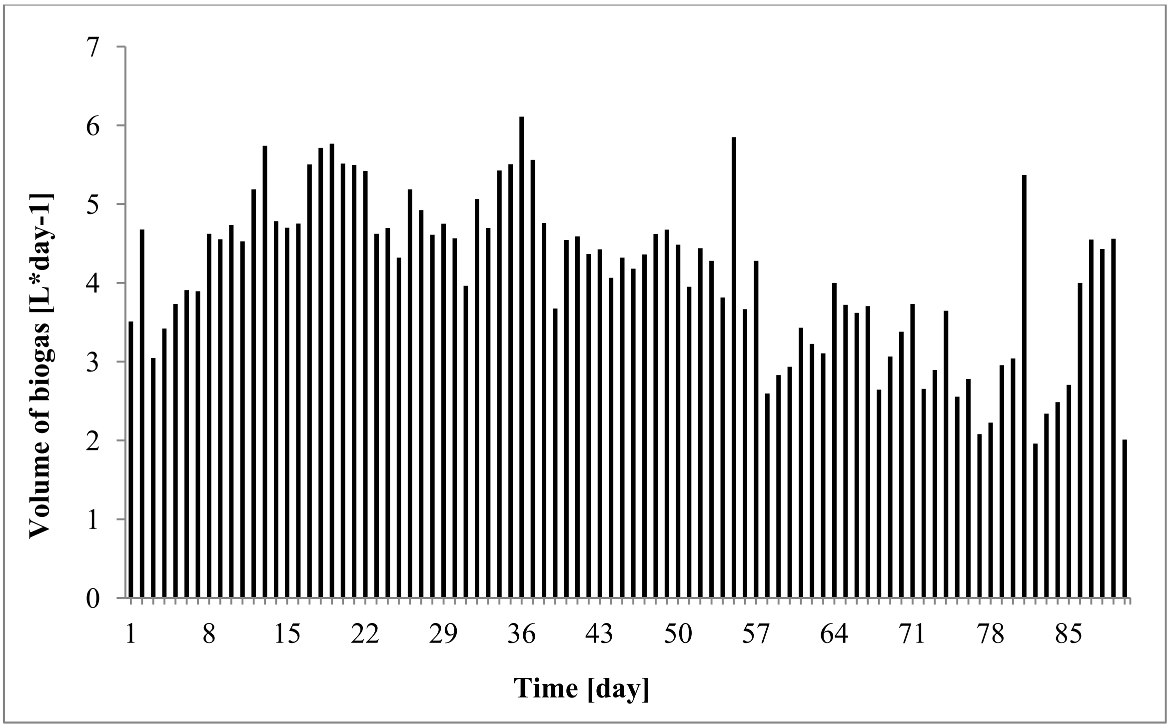


Fig 4.12 Daily biogas production of PM+SMC semi-continuous treatments

In the first week of fermentation, the biogas production led a sharp increase and reached the stable range from the 2nd week onwards. The daily biogas production ranged from 5 ÷ 6 L.day^{-1} from the 2nd week up to the 57th day. After the 68th day, the daily biogas production remained 4.8 L.day^{-1} in average with some peak values, implying that digested materials still contained some degradable material. In a similar study, Kaparaju and Rintala (2005) also agreed that in order to optimize methane production in a typical co-digestion process, the digestions should perform with either long hydraulic retention time or long substrate retention time.

The similar situations happened to the treatment of PM+SMC. The biogas production followed a sharp increase in the first week and reached a stable range (4 ÷ 5 $L.day^{-1}$) in the second week. However, from the 57th day onwards the gas production decreased and reached an average value of 3.2 $L.day^{-1}$ up to the ending experimental period.

In both of the treatments, the decrease in gas production at the later phase could be explained by the presence of un-degradable materials in the substrates. After feeding, some materials floated to the surface of the substrates. The floating materials gradually resulted in scum that prevented gas release from the substrate onto the upper part of digester. For a while, some pieces from the scum were fermented and combined with new feeding, thereby causing peak values at the later phase. Even though the feeding work acted as the agitation of the digesters, it could not break the scum at the surface of the substrate.

4.4.2 pH and alkalinity

The pH and alkalinity values of the semi-continuous treatments were recorded for the first 7 weeks. The pH ranged from 6.7 ÷ 7.8 (for the treatment of PM+WH) and from 6.5 ÷ 7.5 (for the treatment of PM+SMC), which is not much different from the optimum range 6.6 ÷ 7.6. Conversely, the pH values in the treatment of PM+WH tended to increase gradually while the pH values of the treatment of PM+SMC was in vice versa.

The drop of pH and methane content signifies hydraulic overload, organic overload or insufficient buffering capacity in digesters. In this study, the pH and methane content tended to decrease in the first 7 weeks but the alkalinity remained in stable range. It could be inadequate anaerobic microorganism in the substrate causing low pH and methane content.

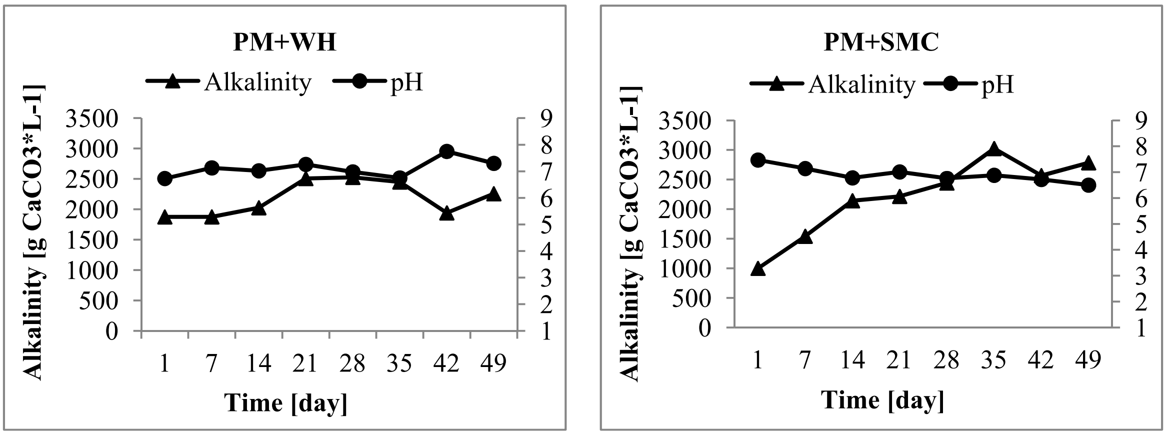


Fig 4.13 Control parameters of the treatments of PM+WH (left) and of PM+SMC (right)

The methane content is to be expected to vary depending on feedstock. For the treatment of PM+WH, the average methane content in the biogas was 60.1% (in range of 53.8 ÷ 64.4%) which was somewhat lower than the average methane content in the PM+SMC treatment 60.5% (in range of 57.5 ÷ 63.6%). Compared to the batch experiments, the methane content in the semi-continuous experiments seems to be higher and stable. In fact, by daily feeding, the semi-continuous treatments supplied more nutrients to microorganism that helped maintain their methanogenic activities.

The methane composition in both co-digestion treatments showed good quality of the produced biogas that can possibly apply for any energy purposes such as cooking, lighting, or electricity generation.

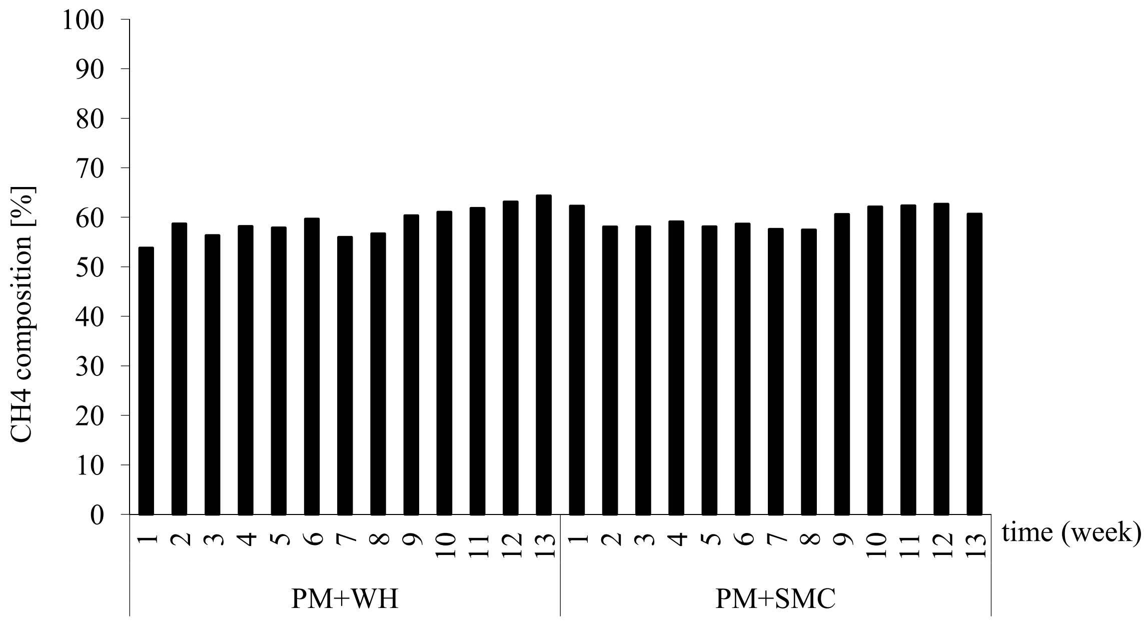


Fig 4.14 Biogas compositions of semi-continuous treatments

4.5 CONCLUSIONS

In this study, anaerobic co-digestion of PM+WH and PM+SMC were implemented in both batch and semi-continuous treatments to test biogas production. The batch experiments were carried out in five differential loading ratios of input materials (100+0, 75+25, 50+50, 25+75, and 0+100) applied for both %PM+%WH and %PM+%SMC, while the semi-continuous treatments were conducted in the mixing ratio of 75%PM+25%WH and 75%PM+25%SMC. All the treatments were set up in triplicate to increase the reliability of the experiment. The findings were recorded as follows:

- For the batch treatment of PM+WH, biogas yield was higher in the treatments with a larger percentage of WH in the mixing ratio. By adding up to 50%WH in the mixed substrate, the produced biogas volume was significantly different in the treatment fed with solely 100%PM. Water hyacinth is obviously a highly potential supplement material to feed into biogas plants, even in case of no pig manure supply available at farming households.

- By mixing PM and SMC in the batch treatments, the higher percentage of SMC in the mixture ratio led to the lower biogas yield in the treatments. However, the results showed that in case of SMC making up 75% of the mixed substrate, the gained biogas volume was not significantly different compared to the treatment fed solely with 100%PM. As such, spent mushroom compost is possibly an acceptable additional material for the anaerobic fermentation in case the pig manure is in short.
- In the treatments of PM+WH and of PM+SMC, the average produced biogas was 5.3 $L.day^{-1}$ and 4.1 $L.day^{-1}$, respectively, in the experimental conditions. These values accounted for about 1/5 to 1/4 of the digester volume which is equivalent to the real biogas plants currently applied in the MD with the daily gas production of 1.0 to 1.2 m^3 over the 4 m^3 digester volume. The produced biogas had good quality due to the average methane content in the biogas over 60% in both the treatments which is significantly possible for cooking and lighting.
- Additionally, these semi-continuous treatments remained in good operation up to the 90^{th} day of the fermentation without any special agitating method application. This is a good testing because the agitating set has not been installed to all of the current biogas plants in the MD, except for the EQ2 model. At present, part of the substrate of the biogas plants currently operating in the MD accumulates at the base of the biogas plants fed with pig manure for years due to no agitating method application. The experiments proved that in case of co-digestion of PM+WH and of PM+SMC with up to 25% biomass, the digester could operate very well for at least 3 months without any application of agitating method.

It evidently concluded that both WH and SMC can provide a viable constituent of a co-digestion feedstock for biogas production in the MD. The finding of these potentially additional input materials into biogas plants besides PM helps open up the opportunities for local farmers to optimize their existing biogas plants in the event of lack of PM, thereby encouraging other local farmers to invest in construction of a biogas plant. By co-digestion of PM and the aforementioned biomass, biogas plants not only treat PM but also help salvage densely-populated WH on the canal system of the rural MD and reuse the agricultural waste of SMC to generate more income as well as protect the living environment. Moreover, the biogas generation of the co-digestion as analyzed in this study is significantly good enough to provide farmers with energy for cooking, lighting, etc.

CHAPTER 5. APPLICABILITY OF BIO-SLURRY FROM ANAEROBIC CO-DIGESTION OF PIG MANURE AND WATER HYACINTH / SPENT MUSHROOM COMPOST TO AGRICULTURE AND AQUACULTURE

5.1 FIELD TEST

5.1.1 Bio-slurry characteristics

Bio-slurry is considered as an alternative input to fishponds and an alternative fertilizer for growing plants because of its high organic, nitrogen and phosphorus content. The major characteristics of the bio-slurry taken from the digesters fed with variety of input materials are presented in Table 5.1 to 5.3.

Table 5.1 Characteristics of the bio-slurry from the digester fed with 100%PM

No.	Parameter	Unit	May-22	Jun-12	Jul-03	Jul-31	Aug-24
1	pH		6.42	6.58	6.53	6.48	6.60
2	VSS	mg/L	-	-	815	2168	4634
3	TS	mg/L	-	-	1695	9852	11340
4	BOD_5	mg/L	954.1	435	360	865.9	1125.4
5	COD	mg/L	7896	3600	1568	5250	27451
6	TKN	mg/L	555.3	369.6	280	655	689
7	TP	mg/L	100.32	182.80	56.39	104.67	153.29
8	K	mg/L	174.38	166.26	100	-	-
9	Total Coliform	MPN/100mL	1.1×10^7	4.6×10^4	4.6×10^7	9.3×10^7	-
10	Salmonella	MPN/100mL	11	ND	ND	15	-

Note -: no values recorded

ND: not detected

The comparison on the characteristics of various types of the bio-slurries as displayed in the above tables indicates that there were significantly different mean-values of the characteristics between the digesters fed with various input materials (except the total phosphorus value). The difference on the bio-slurry's characteristics was divided into three groups depending on the significant difference in their mean-values between the digesters. The first group included VSS, TS, TP and K whose values were ranged in ascending order in the digester of 100%PM, of 90%PM+10%SMC, and of 90%PM+10%WH. The second group included pH, COD and TKN whose values were ranged in ascending order in the digester of 100%PM, of 90%PM+10%WH, and of 90%PM+10%SMC. The last was BOD_5

value which was ranged in ascending order in the digester of 90%PM+10%SMC, of 100%PM, and of 90%PM+10%WH. The result of Duncan's Multiple Range Test from various digesters' bio-slurry characteristics as showed in Table 5.4.

Table 5.2 Characteristics of the bio-slurry from the digester fed with 90%PM+10%WH

No.	Parameter	Unit	May-22	Jun-12	Jul-03	Jul-31	Aug-24
1	pH		6.53	6.76	6.98	6.54	6.83
2	VSS	mg/L	-	-	3817	9624	11320
3	TS	mg/L	-	-	6097	12781	13173
4	BOD_5	mg/L	856.3	2085	1942.5	1773.5	1806.3
5	COD	mg/L	7082	50400	43904	48752	51387
6	TKN	mg/L	1827	1253	2534	2754	2645
7	TP	mg/L	113.37	178.41	75.72	119.32	231.18
8	K	mg/L	389.11	175.52	340	-	-
9	Total Coliform	MPN/100mL	1.1×10^5	2.4×10^5	1.1×10^6	9.3×10^8	-
10	Salmonella	MPN/100mL	4	ND	ND	230	-

Note *-: no values recorded*

ND: not detected

Table 5.3 Characteristics of the bio-slurry from the digester fed with 90%PM+10%SMC

No.	Parameter	Unit	May-22	Jun-12	Jul-03	Jul-31	Aug-24
1	pH		6.65	6.56	6.63	6.72	6.76
2	VSS	mg/L	-	-	7244	8942	10245
3	TS	mg/L	-	-	14555	15957	17921
4	BOD_5	mg/L	143.2	262.5	285	1274.9	1548.1
5	COD	mg/L	3934	7200	4704	38480	48444
6	TKN	mg/L	513	217	434	2556.7	2478.6
7	TP	mg/L	132.3	167.11	169.62	187.56	232.77
8	K	mg/L	431.94	302.92	330	-	-
9	Total Coliform	MPN/100mL	1.1×10^7	4.6×10^5	4.6×10^5	4.6×10^8	-
10	Salmonella	MPN/100mL	4	ND	ND	4	-

Note *-: no values recorded*

ND: not detected

Table 5.4 The different on bio-slurry characteristics at variety digesters

Treatment	TP	VSS	TS	K
100%PM	119.494 m	2539.000 c	7629.000 e	146.880 n
90%PM+10%WH	143.600 m	8253.667 d	10683.667 ef	301.543 no
90%PM+10%SMC	177.872 m	8810.333 d	16144.333 f	354.953 o

Treatment	pH	COD	TKN	BOD_5
100%PM	6.522 a	9153.000 i	509.780 k	748.080 g
90%PM+10%WH	6.728 b	40305.000 j	2202.600 l	1692.720 h
90%PM+10%SMC	6.664 ab	20552.400 ij	1239.860 kl	702.740 g

Note: the means followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.

5.1.2 Calculation for bio-slurry volume used as plant fertilizers

Based on the nutrients content of each type of the bio-slurries, the volume of bio-slurry applied for the treatments was calculated to make an equivalent type and amount of nutrients to those contained in the IF applied for the IF treatment. Due to high N content in bio-slurry, the needed volume of bio-slurry for planting was calculate based on the value of N. There were two groups of treatments set up with or without P and K supplement.

- Treatment of PM0, of SMC0, and of WH0: applied bio-slurry only based on N nutrient
- Treatment of PM1, of SMC1, and of WH1: applied bio-slurry based on N nutrient plus P and K supplement

Table 5.5 Bio-slurry volume and supplementary inorganic fertilizers for each treatment

Treatment	Day	Bio-slurry ($mL.0.09m^{-2}.day^{-1}$)	Additional water ($mL.0.09m^{-2}.day^{-1}$)	Additional supper phosphate* ($mg.0.09m^{-2}.day^{-1}$)	Additional KCl* ($mg.0.09m^{-2}.day^{-1}$)
SMC0/ SMC1	0 ÷ 10	314	1036	930.3	-
	11 ÷ 15	27	1323	46.6	-
	16 ÷ 20	116	1234	-	-
	21 ÷ 25	116	1234	-	-
	26 ÷ 30	13	1337	30.4	64.0
	31 ÷ 42	-	1350	-	-
WH0/ WH1	0 ÷ 10	88	1262	894.9	76.0
	11 ÷ 15	8	1342	42.2	-
	16 ÷ 20	20	1330	31.6	1.4
	21 ÷ 25	20	1330	31.6	17.8

	26 ÷ 30	40	1310	35.2	69.4
	31 ÷ 42	-	1350	-	-
PM0/PM1	0 ÷ 10	290	1060	774.3	55.1
	11 ÷ 15	25	1325	27.8	-
	16 ÷ 20	68	1282	-	-
	21 ÷ 25	68	1282	-	4.8
	26 ÷ 30	21	1329	27.8	65.0
	31 ÷ 42	-	1350	-	-

Notes **: applied for only SMC1, WH1 and PM1 treatments*

-: no nutrients supplemented during that period

In this study, the bio-slurries were applied with the corresponding volume to the plants twice a day on a daily basis throughout the planting time. Meanwhile, the inorganic fertilizers were applied only 5 times for the whole planting time according to a fertilization schedule, and in this case water was supplied to the plants twice a day (in the morning and afternoon) on a daily basis so as to reach the required watering volume but there was no watering on rainy days.

5.1.3 Calculation for fishpond supplied with bio-slurry

The volume of bio-slurries loaded into fish nets was calculated based on COD values of each bio-slurry type. Each fish net was supplied with the amount of bio-slurry equivalent to the value of 150 kg COD.ha^{-1}.day^{-1} per 1 m² water surface of the fist net. Bio-slurry was applied to fish nets twice a day in accordance to the pigpen cleaning daily routine. In parallel, commercial food was also applied twice per day at the same time as the bio-slurry was applied. The volume of bio-slurry fed into fish nets daily was presented in Table 5.6.

Table 5.6 Volume of bio-slurry fed into fish nets

No.	Treatment	Volume of applied bio-slurry (L.m^{-2}.day^{-1})		
		Jun-27 to Jul-03	Jul-03 to Jul-31	Jul-31 to Aug-22
1	PM1	4.16	9.56	2.86
2	PM2	2.08	4.78	1.43
3	WH1	0.30	0.34	0.68
4	WH2	0.15	0.17	0.34
5	SMC1	2.08	3.18	0.40
6	SMC2	1.04	1.59	0.20

5.2 RESULTS ON LEAF MUSTARD PLANTING

After two weeks of planting, almost all the leaf mustard plants in the control treatment (without fertilizer) died. Therefore, there is no discussion on the control treatment results in this study.

The statistical analysis of the output results showed that the growing rate of the leaf mustard (consisting of plant weight, plant height, leaf length, and leaf width) in the experiments with and without P and K supplement was not significantly different at 5%. For that reason, this study only presents and discusses the outputs of the treatment of PM0, of SMC0, of WH0 and of IF.

5.2.1 Changes in soil fertility

Before planting the leaf mustard, there were no differences in the soil humidity and nutrient content among the fertilizer treatments due to the homogenous form of soil prepared at the initial phase. However, the soil humidity in all the fertilizer treatments became higher after growing the leaf mustard, in which the treatment supplied with IF got the smallest change in the soil humidity while the SMC0 applied treatment took the biggest change. Similarly, there were variations on the soil humidity in the treatments with daily watering with various types of substrates. Compared to the other substrates, the substrate from the SMC0 treatment containing rice straw content acted as the best cover layer avoiding water evaporation through soil surface. In this connection, Arnold (2009) discussed that co-substrate biogas sludge with rice straw performed better than sludge without straw. This is most likely due to the fact that rice straw brought in structure and improved aeration and the C/N ratio was also adjusted. The substrates from the PM0 and WH0 treatments also equally brought in a positive prevention from water evaporation. By contrast, the IF treatment was applied no substrate but only daily watering that offered good conditions for water evaporation through soil surface.

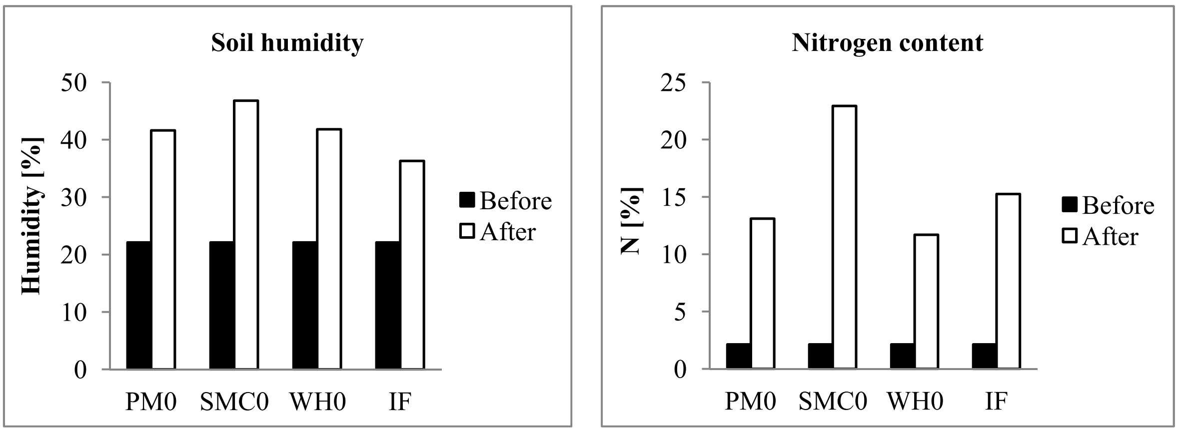
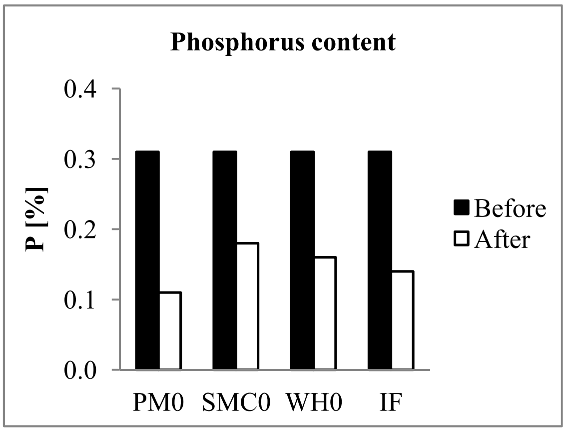


Fig 5.1 Soil humidity (left) and nitrogen content (right) in different treatments

The amount of nitrogen remaining in the soil after the leaf mustard was harvested was larger than before the planting. Nitrogen contained in the harvest soil was larger than the initial nitrogen by 5.5, 6.2, 7.2, and 10.8 times in the treatment of WH0, PM0, IF and of SMC0 respectively. The best growing output of leaf mustard obtained in the SMC0 treatment implied that the plants absorbed more nitrogen in this treatment than in the other treatments. Nitrogen was supplied for each treatment with the same amount but it remained the highest in the SMC0 treatment. This could be due to the loss of nitrogen through soil surface by evaporation. As such, as similar to soil humidity, among the substrates applied, SMC0 substrate is the best fertilizer to minimize loss of nitrogen by evaporation.

In addition, that nitrogen remained larger in soil after the harvest of leaf mustard than before the planting signified that there could have been more nutrient supplied than the needed nutrient for the plants. In fact, the inorganic fertilizer scheme guidelines always suggest to supply a larger amount of nutrients than needed to plants so as to ensure the plant yield in case of loss of nutrients. Taking such a recommendation concerning fertilizer application, farmers will waste money on excessive fertilizers. The testing results showed that application of organic fertilizers for crops could help improve this "stork neck", thereby bringing in more income for growers.



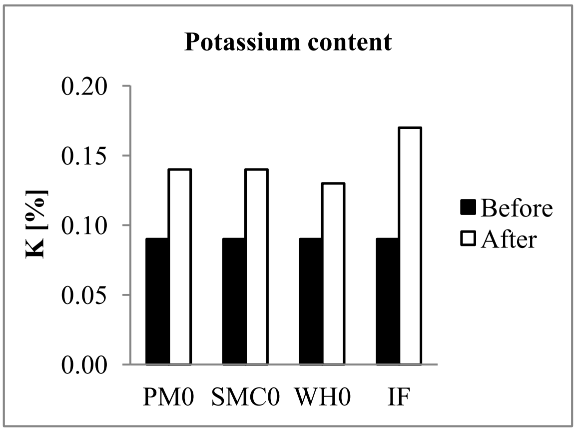


Fig 5.2 Phosphorus (left) and potassium (right) content in different treatments

Differences in phosphorus among the fertilizer treatments were not much, ranging from 0.11 ÷ 0.18%, but lower than the initial phosphorus value. The results showed that leaf mustard plant was good at absorbing phosphorus. In fact, phosphorus is an essential part of the process of photosynthesis and gets involved in the formation of sugars, starches, etc. Phosphorus will be strongly absorbed at the time of plant maturation or blooming. Besides, even though the phosphate was applied into the treatment IF as much as recommended, the phosphate value after the harvest was lower than before the planting. The explanation for this result is that there could be a significant loss of phosphorus contained in the inorganic fertilizer by discharging together with rainfall or by evaporation through soil surface.

The soil potassium was almost higher in all the fertilizer treatments after the planting of leaf mustard but got the highest value in the IF treatment. This result indicated that the bio-slurries contained more potassium than the need of the plants. As such, in case of application of bio-slurries to plant growing, it is not necessary to fertilize the plants with extra potassium.

5.2.2 Plant growing

The bio-slurries applied treatments could increase the plant weight more than the treatment only supplied with inorganic fertilizers. The leaf mustard yield of 21.1, 9.1, 8.7, and 3.9 tons fresh biomass per ha was observed in the treatment of SMC0, of PM0, of WH0, and of IF respectively for a 43 day growing period. The increased yield pertaining to the leaf mustard fed with bio-slurry could be attributed to the improvement of soil nutrients. In this connection, Garg *et al*. (2005) found that amendments of soil with biogas slurry could be attributed to the improvement of soil physical properties in terms of lower bulk density, higher hydraulic conductivity and greater moisture retention of soil.

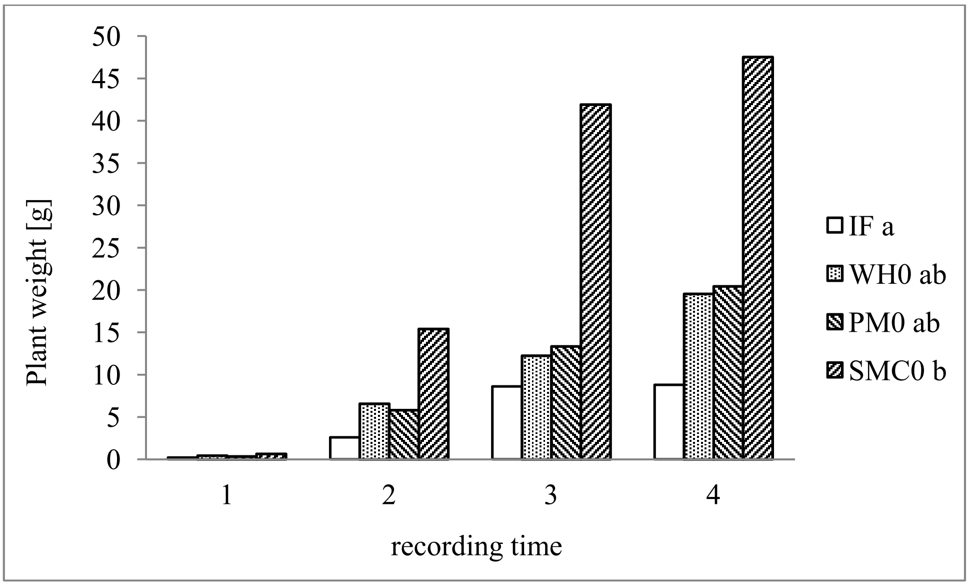


Fig 5.3 Plant weight of leaf mustard at different fertilizer treatments

Note: Treatments followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.

In addition to the highest quantity of nitrogen and phosphorus remaining from the SMC0 treatment, the highest leaf mustard yield was gained in this treatment. This result showed that nitrate nitrogen (NO_3) from commercial fertilizer sources has less effect on plant yield compared to ammonia-N from the bio-slurry source, especially in case the applied bio-slurry taken from the biogas plant fed with PM+SMC mixture.

In respect with the results of plant height, the application of bio-slurry helped shorten the cultivation time of leaf mustard. The WH treatment was the earliest flowering on the 35^{th}

day, the PM treatment started to flower on the 38th day, and the other treatments had flower formation from the 40th day onwards. The leaf mustard plants must be harvested for sales before their flower formation. It means watering with bio-slurry could save from 5 to 10 days of leaf mustard planting time. Actually, in this study, it was observed visually that the leaves of the plants began to dry and curl up since the flower formation occurred. This phenomenon strongly confirmed and signified that the plants were so mature and they should have been harvested earlier.

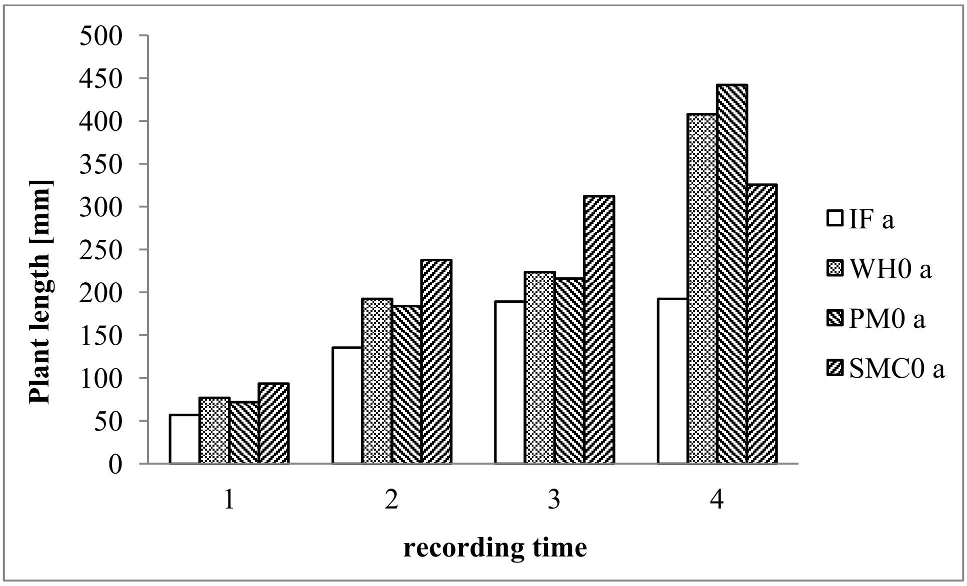


Fig 5.4 Plant height at different fertilizer treatments

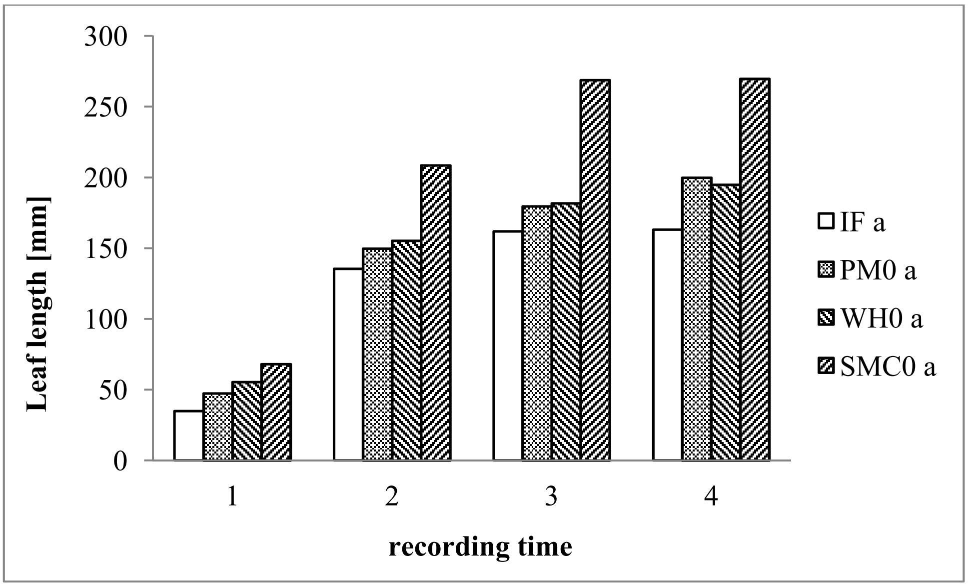


Fig 5.5 Leaf length at different fertilizer treatments

Note: Treatments followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.

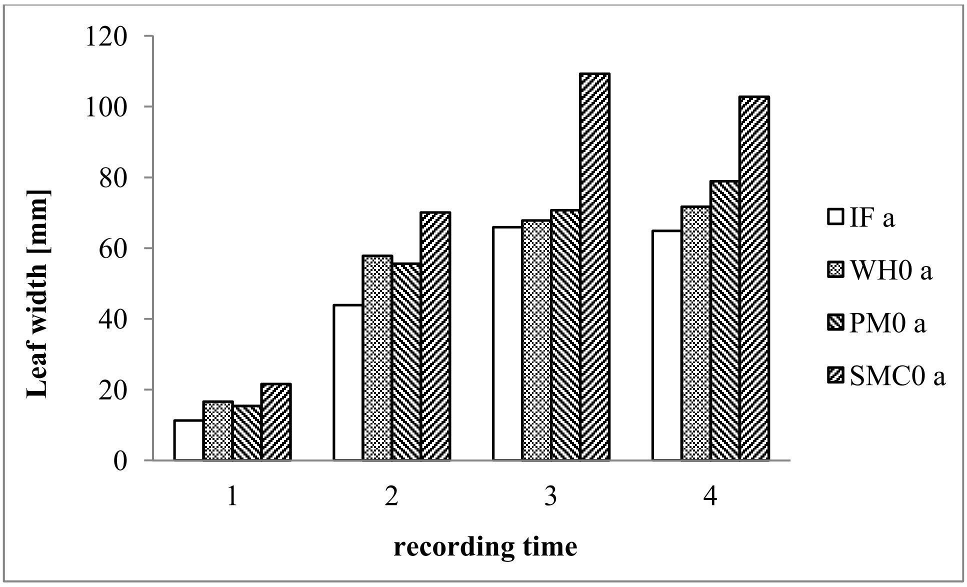


Fig 5.6 Leaf width at different fertilizer treatments

Note: Treatments followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.

On average, the leaf mustard plant dry matter content reached 8.4%, 6%, 9.3%, and 7.8% in the treatments of IF, of SMC0, of WH0, and of PM0 respectively. In the MD, assuming that irrigation is available throughout the year, in case of application of bio-slurries to leaf mustard growing as prescribed in this study, the yield will be 11.5, 7.3, and 6.4 tons of leaf mustard dry matter per hectare for the application of the bio-slurry from digesters fed with PM+SMC, with PM+WH, and with PM alone without an addition of any inorganic fertilizers, respectively.

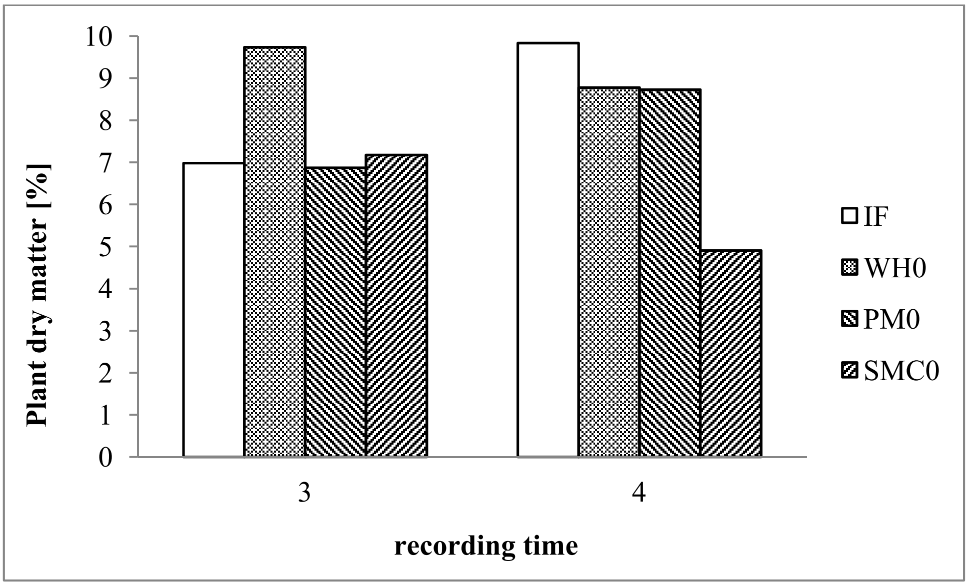


Fig 5.7 Plant dry matter content

The Salmonella contaminated in the leaf mustard plants which were watered with different bio-slurries was tested. There was no Salmonella found contaminated in the treatments of IF and of WH0 in the first test, while in the second test Salmonella was found only in the treatment of WH0. The presence of Salmonella in some of the treatments may pose a risk to human health, particularly in case of supply of bio-slurry to such plants as vegetables which are normally eaten fresh.

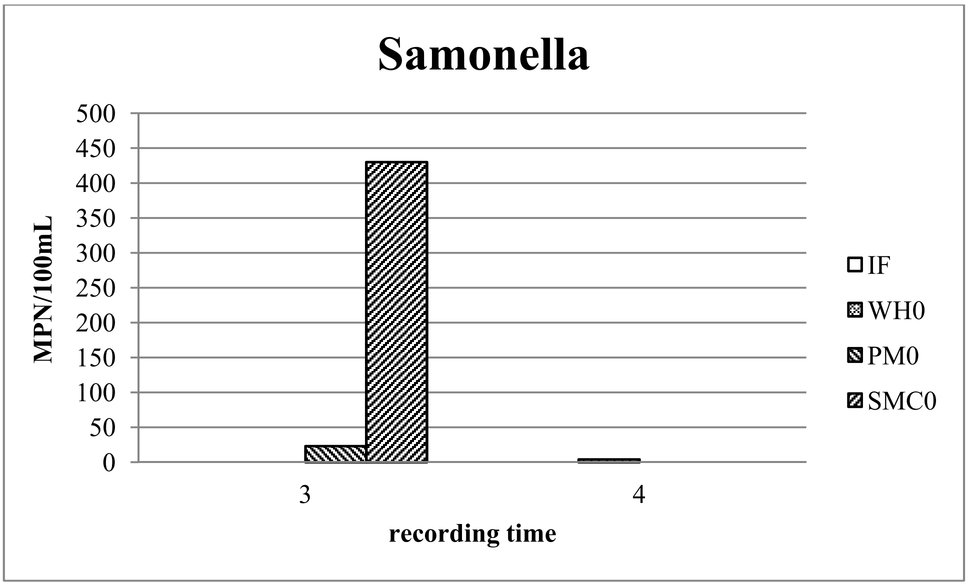


Fig 5.8 Salmonella contamination

5.3 RESULTS ON TILAPIA FISH RAISING

5.3.1 Fish pond characteristics

According to Hepher (1962), the primary production of fertilized fishponds was 4 to 5 times higher than that of unfertilized fishponds. In fact, by supplying organic fertilizers into fishponds, it contains more essential nutrients than needed for fishponds productivities.

In this study, it was observed that in all the experiments, pond factors remained at optimal values required for fish growth and survival. Almost all the factors from the treatments of SMC and of WH were higher than those from the treatment of PM that showed more nutrients remained in experiments took bio-slurries from co-digestion biogas plants. There was another study recorded higher fish production in case of applying organic fertilizers into fishponds [Yadava and Garg, 1992]. These nutrients bring in food for the algae and zooplankton, which in turn are eaten by the fish.

By applying bio-slurry into fishponds the water body became turbid, which may be beneficial to the fishes [Bruton, 1985]. The bio-slurry could maintain constant nutrients availability for algae and zooplankton growing in the fishpond. There was no test for algae and zooplankton from the fishpond in this study, but it has been reported that these forms were observed in greater numbers in the ponds where supplied with biogas effluents [Balasubramanian and Bai, 1994]. The authors also recorded that the bio-slurry not only directly affected fish growth, but also the nutrient accumulation could remain several times after ceasing applying the bio-slurry into fishpond.

Table 5.7 Hydro-biological characteristics of water body in fishpond

Treatment		VSS (mg/L)	TS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	TP (mg/L)
100%PM	PM0	1.23	292	17.50	4000	17.45	1.43
	PM1	1.25	324	34.56	4800	25.73	1.87
	PM2	1.67	354	25.78	4000	19.34	1.53
90%PM+ 10%SMC	SMC0	1.23	292	17.50	4000	17.45	1.43
	SMC1	2.70	318	58.75	3600	30.40	1.79
	SMC2	2.45	376	56.25	8000	36.57	2.12
90%PM+ 10%WH	WH0	1.47	312	26.25	4800	23.57	1.83
	WH1	3.29	342	62.67	5600	29.65	2.10
	WH2	2.84	304	42.50	8000	23.73	1.77

Note: As both of the treatment of 100%PM and of 90%PM+10%SMC were arranged at the same fishpond, only one control treatment for these two experiments was set up. As a result, the recorded values of PM0 and SMC0 treatments were the same.

5.3.2 Fish growing

During the experimental period, the number of fish alive was frequently recorded based on the number of fish died floating visually on the water surface. And at the last record, all the experimental nets were hauled in and the number of living fish was checked.

Table 5.8 Number of living fish in the experiments

Food apply / Treatment	No food (0)	Only bio-slurry (1)	Bio-slurry + CF (2)	Only CF (3)	Average
100%PM	60%	90%	100%	90%	85%
90%PM+10%WH	80%	97%	80%	100%	89%
90%PM+10%SMC	60%	90%	87%	90%	82%
Average	67%	92%	89%	93%	

As regards the comparison of the number of living fish in the treatments, there were more fish alive in the treatments supplied with food than the control treatment with no food supply. However, there was a similar average value of living fish in the treatments which were supplied with only bio-slurry, with bio-slurry combined with commercial food, and with commercial food alone.

The number of fishes still living after 52 culture-days was not significantly different between the treatments. Obviously, this result gives to farmers a chance to use the biogas plant with co-digestion pig manure and biomass.

Table 5.9 Fish growth of the supplied bio-slurry from 100%PM digester

Treatment	Fish weight (g)	Fish length (cm)	Fish width (cm)
PM0	10.500 a	6.450 c	2.550 ef
PM1	9.295 a	6.192 c	2.465 e
PM2	17.740 ab	7.548 cd	3.047 fg
PM3	21.445 b	8.332 d	3.245 g

Note: The means followed by a common letter are not significantly different at p ≤ 0.05 based on Duncan's Multiple Range Test.

The fish growth factors showed that the highest values came from the treatment fed with 100% commercial food, followed by the treatment fed with 50% bio-slurry + 50% commercial food, the control treatment, and the treatment fed with 100% bio-slurry. The result from Duncan testing displayed that there was no significant difference between the treatment fed with 100% commercial food and the treatment fed with 50% bio-slurry + 50% commercial food. In a previous study on the integrated pig - fish production in the MD, Duong *et al*. (2010b) recorded that the fish yield from a treatment applied biogas effluent + supplemental food has been higher than a treatment applied biogas effluent only.

In this study, similar results were recorded for the groups of experiments supplied with bio-slurry from 90%PM +10%SMC and from 90%PM+10%WH digesters. The fish growth rate reached highest in the treatment fed with 100% commercial food, followed by the treatment fed with 50% bio-slurry + 50% commercial food, the treatment fed with 100% bio-slurry and the last was the control treatment.

Table 5.10 Fish growth of the supplied bio-slurry from 90%PM+10%SMC digester

Treatment	Fish weight (g)	Fish length (cm)	Fish width (cm)
SMC0	10.500 a	6.450 c	2.550 e
SMC1	10.963 a	6.553 c	2.580 e
SMC2	20.147 ab	7.920 cd	3.200 f
SMC3	21.445 b	8.332 d	3.245 f

Note: The means followed by a common letter are not significantly different at p ≤ 0.05 based on Duncan's Multiple Range Test.

Table 5.11 Fish growth of the supplied bio-slurry from 90%PM+10%WH digester

Treatment	Fish weight (g)	Fish length (cm)	Fish width (cm)
WH0	10.500 a	6.450 c	2.550 e
WH1	10.558 a	6.532 c	2.560 e
WH2	17.733 ab	7.558 cd	3.038 ef
WH3	21.445 b	8.332 d	3.245 f

Note: The means followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.

In this study, there was no difference in fish growth between the control treatment and the bio-slurries supplied treatments due to ill control conditions at farmer's fishponds. Enclosing the experiment nets by PVC film could affect the growing process of algae inside the fish nets, thereby affecting food supply source for the fish. In contrast, even though the control treatment was supplied with neither food nor bio-slurry, the nutrients from water column in the fish pond was be able to exchange into these fish nets, facilitating the development of algae which became food source for the fish.

In regard to the experiments supplied with bio-slurry from 100%PM digester, the fish growth value of the treatment fed with 100% bio-slurry was lower than that of the control treatment. On the contrary, the fish growth value of the treatment fed with 100% bio-slurry from 90%PM+10%SMC or 90%PM+10%WH digester was higher than that of the control treatment. In fact, the treatment supplied with 100% bio-slurry could be supplied more nutrients than the treatment without any feeding. The different trends happened due to both of the groups of experiments supplied with bio-slurry from 100%PM and 90%PM+ 10%SMC digester being set up at the same pond. And this pond daily received the effluent from the digester of 90%PM+ 10%SMC (equivalent to about 150 L effluent discharged to 60 m² surface water of this fish pond) that supplied more nutrients to algae and zooplankton population outside of the experiment nets. Comparing the fish growth within the group of experiments supplied with bio-slurry from 90%PM+10%SMC digester, the fish growth of treatment fed with 100% bio-slurry was higher than that of the control treatment, while the fish growth went in vice verse in the experiments supplied with bio-slurry from 100%PM digester.

In this study, the fish nets were loaded by bio-slurry volume based on its COD values. Edwards *et al*. (1988) recorded that there was an increase in both the rate of growth of stocked fish and their mean size with an increase in organic loading of the bio-slurry. Hence, in case farmers have more bio-slurry, they can supply more bio-slurry into fishpond but not exceed the value of 150 kg COD.ha^{-1}.day^{-1}.

After 52 days of fish culture, the experiments supplied with 50% bio-slurry + 50% commercial food produced the net production of fish of 2.3, 2.7, and 2.7 tons.ha^{-1} in the treatment of PM, of PM+SMC, and of PM+WH respectively. The experiments supplied with 100% bio-slurry produced the net production of fish of 0.8, 0.8, and 1.0 tons.ha^{-1} in the treatment of PM, of PM+SMC, and of PM+WH respectively. Comparing fish growth between the treatments of supplied bio-slurries, both of the groups of experiments related to the supplied 100% bio-slurry and 50% bio-slurry + 50% commercial food showed that the highest fish growth rate was recorded in the treatment of 90%PM+ 10%WH, of 90%PM+10%SMC, and of 100%PM. It means by feeding into fishpond with the bio-slurry from co-digestion of PM+WH or PM+SMC, it could increase the fish yield more than the treatment supplied with bio-slurry from the digester inputted only by pig manure.

Table 5.12 Fish growth pertaining to the supplied 100% bio-slurry

Treatment	Fish width (cm)	Fish length (cm)	Fish weight (g)
PM1	2.465 a	6.192 b	9.295 c
WH1	2.560 a	6.532 b	10.558 c
SMC1	2.580 a	6.553 b	10.963 c

Table 5.13 Fish growth pertaining to the supplied 50% bio-slurry + 50% commercial food

Treatment	Fish width (cm)	Fish length (cm)	Fish weight (g)
PM2	3.047 a	7.548 b	17.733 c
WH2	3.038 a	7.558 b	17.740 c
SMC2	3.200 a	7.920 b	20.147 c

Note: The means followed by a common letter are not significantly different at $p \leq 0.05$ based on Duncan's Multiple Range Test.

As regards the group of experiments supplied with 100% bio-slurry and that of 50% bio-slurry + 50% commercial food, the fish growth was not significantly different ($p \leq 0.05$). It clearly confirmed that the fish could be raised by only feeding 50% commercial food and 50% bio-slurries but the fish yield was not significantly different from feeding the fish with 100% commercial food. In other words, farmers can save at least 50% expense cost on fish food when raising fish in an integrated pig - fish culture system.

Some researchers recorded higher growth rates of fish in ponds fertilized with biogas effluent than with manure [Kaur *et al*. 1987; Pich and Preston, 2001]. By contrast, Duong *et al*. (2010b) recorded fish yield from treatment applied with biogas effluent lower than from treatment applied with pig waste only. In this study, the treatments in which fresh PM was applied directly were not arranged due to hygienic conditions of this kind of feeding.

In this study, there was no opportunity to study deeply on fish yield between the treatments supplied with bio-slurry from 90%PM+10%SMC digester and 90%PM+10%WH digester. It was unknown why higher fish growth was recorded in the treatment supplied with bio-slurry from PM+SMC digester than from PM+WH. But according to ACRSP (2006), rice straw can be used to increase fish production through the development of bacterial biofilm and periphyton. In addition, by applying rice straw mat into fishpond, 87 genera of phytoplankton were identified, belonging to the following groups in order to total number: *Bacillariophyceae, Chlorophyceae, Cyanophyceae* and *Euglenophyceae*. Three genera, namely *Cyclotella*, *Microcystis* and *Euglena,* were dominant among all identified genera. Twenty genera of zooplankton were identified among those *Rotifera* and *Crustacea* were the most dominant groups, whereas *Brachionus* and *Nauplius* were the dominant genera. Estimating when applied bio-slurry from PM+SMC digester, there were some of mentioned phytoplankton and zooplankton which benefit for fish raising present in these experimental nets. And these populations caused difference as mentioned above.

5.4 CONCLUSIONS

Bio-slurry from a co-digestion biogas plant of PM and biomass (WH and SMC) is possible to use as organic fertilizers not only for vegetable planting but also for fish culture. The results of leaf mustard planting as analyzed in this study showed that application of bio-slurry of the co-digestion to planting gave a better output compared to that of inorganic fertilizers application. Actually, the harvest yields of leaf mustard were 5.4, 2.3 and 2.2 times higher in the treatment supplied with inorganic fertilizers from co-digester of PM+SMC, of PM and of PM+WH respectively.

In addition to its contribution to higher yield of the plant, the bio-slurry can prevent loss of nutrients by evaporation and supply the soil with safe organic fertilizers as well. In parallel, plant watering with bio-slurry can accelerate the flower formation process of the plants, thereby shortening cultivation time. As such, bio-slurries from the co-digestion can be potential for plant cultivation. However, due to the fact that the Salmonella was found in some leaf mustard planting treatments even in case the bio-slurry was applied directly to the foot of the plants, it is strongly recommended that farmers should apply bio-slurry to fruit trees or only kinds of vegetables which are need to cook before eating.

For Tilapia fish culture, the experiments supplied with 50% bio-slurry + 50% commercial food produced the net production of fish of 43.81, 51.50 and 51.92 $kg.ha^{-1}.day^{-1}$ in treatment of PM, of PM+SMC and of PM+WH respectively. These growing rates were not significantly different in the treatment of fish raising with 100%CF. This means farmers can raise fish by only feeding 50% commercial food and 50% bio-slurry from the co-digestion biogas plant and get a similar output to that of feeding fish with 100%

commercial food. This result appears significant to farmers in the MD where the farmers normally spend about 1,700,000 VND for commercial food for one crop of Tilapia fish that takes six months on average. It means in case of using 50% bio-slurry for fish feeding, farmers can save about 1.7 million VND per year on the cost of Tilapia fish raising.

The experiments supplied with 100% bio-slurry produced the net production of fish 14.3, 14.8 and 18.8 $kg.ha^{-1}.day^{-1}$ in the treatment of PM, of PM+SMC, and of PM+WH respectively. These values were significantly different in the treatment raising fish with 100% commercial food but not different in the treatment raising fish with 50% bio-slurry + 50% commercial food. The result could lead to the conclusion that it is possible to raise fish feeding with only bio-slurry from co-digestion biogas plants, but it is worth noting that the fish need more time to increase their weight in such a case.

Furthermore, applying bio-slurry into fishpond can keep the optimal pH range for fish survival. Also, the application of bio-slurry to fishpond can avoid algae bloom which occurs if fresh manure applied, maintaining DO value in water body. The fish raising experiments were carried out onsite at farmer's household during the rainy season. When raising fish in dry season, the pH value of water body should be taken into account. Even in rainy season, the pH value from water body in the fishpond was only about 6.31 ÷ 6.62.

Almost the biogas digesters in the MD were built from 4 to 10 m^3. With these volumes, by cleaning work, there are around 150 to 300 L bio-slurry discharged per day. According to its nutrients content, farmers can apply this bio-slurry to small or large scale gardening. In this study, the bio-slurry from the digester fed with PM+SMC, with PM+WH and with PM can be applied for the area of about 950 m^2, 3200 m^2 and 1200 m^2 respectively.

Farmers in the MD conventionally discharge fresh pig manure into their fishponds or for gardening, which causes negative impacts on water sources. Application of the biogas plant for pig manure treatment and the bio-slurry as organic fertilizer into the fishpond or for gardening will help improve the local environment, preventing the practice of using fresh pig manure.

CHAPTER 6. HDPE DIGESTERS - AN INNOVATIVE BIOGAS PLANT MODEL FOR SMALL-SCALE FARMS IN MEKONG DELTA

6.1 PREPARATORY WORKS

6.1.1 HDPE digester processing

The volume of the digester is determined based on the volume of wastes which have to treat. At present, the HDPE lining available in the market is 7.0 m wide and its length can be extended more than 200 m depending on its thickness. The length of the new digester is chosen to be 7.0 m according to the width of HDPE lining. In this study, the digester was manufactured in the HDPE lining of 0.1 cm thickness and the length of 210 m. By this design, the length of the HDPE digester is shorter than the length of a PE digester (10 m) that could save the construction area.

Box 6.1 Calculations for digester volume

The total volume of digester is the sum of the fermented volume and the storage biogas volume.

$$V_{total} = V_{fermentation} + V_{biogas} \quad (1)$$

The fermented volume was estimated based on the number of pig herds which are commonly raised at farming household. The fermented volume should be:

$$V_{fermentation} = K \times (MW \times AN) \times RT \quad (2)$$

in which

$V_{fermentation}$: fermented volume (m^3)

K: the coefficient dependent to the mixing ratio of pig manure and dilute water

MW: unit manure volume of 6 ÷ 8% pig weight (L/pig herd.day^{-1}) [Loehr, 1984]

AN: number of pig (pig herd)

RT: retention time (day)

In addition, the storage biogas volume has to take in account into total volume of digester. With our experiences on PE digesters, the digester and gas storage should be combined into one part to save area and avoid low pressure and any happening damage of the gas-bag. In the guidelines on biogas emission from enteric fermentation in domestic livestock, Hesse and Luu (2007) suggested this formula applicable for average pig weight of 60 kg:

$$V_{biogas} = LU \times DOI \times DGY \times AN \quad (3)$$

in which

V_{biogas}: volume of produced biogas (m^3 biogas.day^{-1})

LU: livestock unit (= 0.1 LU/pig herd)

DOI: daily organic input (= 3.25 kg ODM.day^{-1}.LU)

DGY: daily gas yield (= 0.48 m^3 biogas.kg^{-1} ODM)

AN: number of pig (pig herd)

For inlet and outlet pipes, unlike PE digesters that require wrapping of the plastic over these pipes, there are two connection joints prepared at both sides of the HDPE digester available to fix with inlet and outlet pipes by the adjusting rings. The HDPE digester is pre-manufactured at factory, then packaged and transported to farming households.

6.1.2 Required materials to install the digester

To support for the HDPE digester installation, farmers need to prepare the following materials which are available in local markets.

- 2 PVC pipes of 200 cm length for each and 14 cm internal diameter.
- 2 adjusting rings to fix the inlet and outlet pipes into the digester.
- PVC hosepipe of 12.5 mm internal diameter (the length depends on the distance from the digester location to the kitchen).
- 2 PVC adapters (male and female) of 12.5 mm internal diameter for gas connection.
- 2 rubber washers (from car inner tube) of 7 cm diameter and 1mm thickness with a 12.5 mm diameter central hole.
- 2 rigid plastic washers of 10 cm diameter and a central hole of 12.5 mm.
- 1 PVC elbow of 12.5 mm internal diameter.
- 3 PVC "T" pieces of 12.5 mm internal diameter.
- 1 transparent plastic bottle and 1 tube of PVC glue.

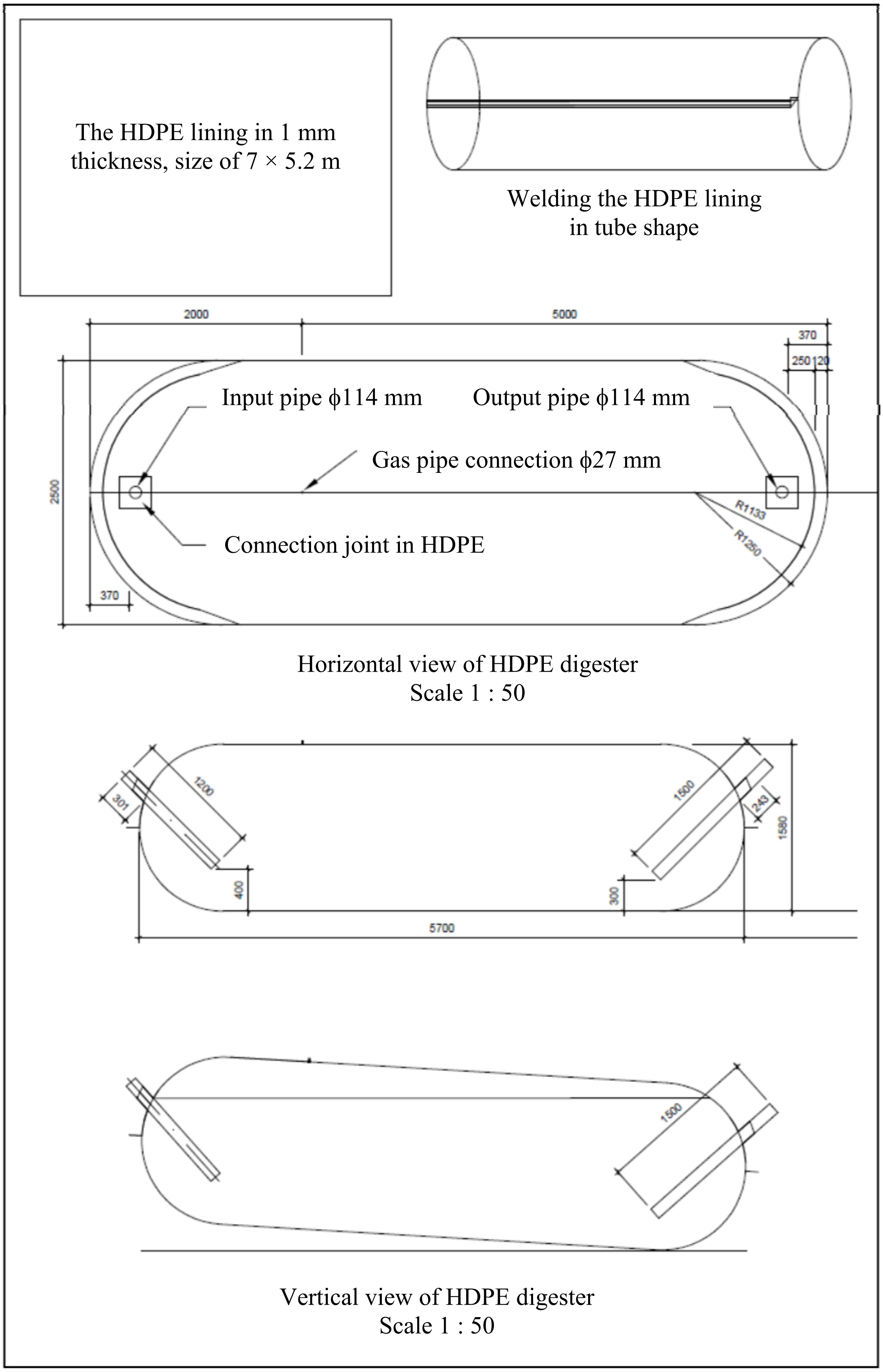


Fig 6.1 The design drawing of the HDPE digester

6.2 INSTALLATION OF THE HDPE DIGESTER

6.2.1 Preparation for installation site

The first step of installation of the digester is to identify the most appropriate location. The location should be close to the pigpen for the convenience of the waste collection. It could be a great advantage if the washing from the pigpen passes by gravity directly to the inlet of the digester.

Once the location is determined, the next step is to determine the size trench needed to be dug. Based on the number of pig herd, the total volume of HDPE digester is defined, and then based on its length of 7 m, the width of the digester will be calculated. Depending on the size of the digester, the upper extremities of the trench should be defined.

When digging the trench, it is important to pay attention to the following issues:

- The floor should have a slope i = 2.5% from the inlet to the exit (this would be 17.5 cm for a digester of 7 m length).
- The trench should excavate with a slope on the bank to avoid soil falling back into the trench in case of heavy rainfall. This slope depends on soil physical parameters.
- The excavated soil should be moved away from the edges of the trench so that the soil will not fall onto the trench.

By applying the HDPE digester with 0.1 cm thickness, it is not so sensitive as a PE digester. To install the HDPE digester into the trench, the sides and the floor of the trench does not need smoothing to avoid protruding stones or roots and no lining the floor and cover on roof of digester by some kind of materials to keep safe for the digester body. This is one remarkable advantage of the HDPE digester. In this study, the HDPE digester was installed onto a pond which located at the farmer's landholding in order to save the farmer the area. However, such an arrangement is not a priority option because the digester will float and thereby cannot keep stable for both the inlet and outlet pipes.

6.2.2 Fixing the gas, inlet and outlet pipes

In case of the HDPE digester, the gas, inlet and outlet pipes can be easily fixed and it is not necessary to care about which one should be installed first. Meanwhile, the installation of PE digesters requires the gas outlet to be fixed first, then the inlet and lastly outlet pipes.

For the inlet and outlet pipes of the HDPE digester, it is simply to attach the ϕ14 cm PVC pipes to both available connection joints instead of wrapping the rubber bands to join the plastic film and the ceramic pipes as it is required to install a PE digester. These PVC pipes are inserted to one-half of its length in the interior of the tube and the connection joint is folded around it. Then the adjusting rings are applied outside of the connection joints which secure tight-fix system of the PVC pipes and the connection joints.

The first step is to mark the gas outlet to a place that should be 1.5 m from the inlet joint and in the center of what will be the top of the digester. This position is chosen so as for the gas to escape by its highest level in the digester body where can avoid the substrate access into gas pipe in case no gas is available inside the digester. The size of the hole is determined by the external diameter of the PVC male adapter. The washer circle is assembled to ensure the male and female adapters fit together smoothly. The male adapter which completes with plastic circle and above this a rubber circle is inserted from within the plastic tube. The female adapter with rubber and plastic circles attached is screwed tightly on the protruding male adapter.

This HDPE digester is easy to fix any holes by simple way. When installing the HDPE digester, the farmers already gets the materials and the guideline on hole-fixing.

6.2.3 Location of the digester into installation site

The whole system of the digester with gas, inlet and outlet pipes is carried to the trench and lowered into the trench in such a way that the gas outlet lies at the top of the tube. Then water is pumped into the digester until the inlet and outlet pipes are covered with water. The air inside the bag is now trapped in the upper part. Also by filling with water, the digester is suspended and extends the inlet and outlet pipes that helps attach both the inlet and outlet pipes to fixed locations.

After fixed the whole system in a stable position, the gas pipeline is connected to the gas outlet pipe of the digester by using PVC glue.

6.2.4 Safety valve (gas escaping valve)

Next, the security valve is installed on the gas pipe at one point between the digester and the biogas appliance. The safety valve is prepared according to the guideline made by Aguilar (2001), and Rodriguez and Preston (xxx).

6.2.5 Taking the gas to the biogas appliances

Unlike the PE digester, the HDPE digester was designed without the separated gas storage bag in order to save the space of gas-storage. In addition, by storing the generated gas inside the HDPE digester, it could help increase the gas pressure, making the biogas applicable not only for cooking but also for lighting. This is one strength of the HDPE digester compared to a PE digester.

Right after the installation, the discharged from a pigpen can go into the digester for fermentation process. It normally takes about 20 ÷ 30 days inside the digester to produce the gas sufficiently and qualified for use. In order to shorten the time of gas generation, it is necessary to feed about 50 liters of sludge taken from an activated digester into the new digester as inoculums. By that way, farmer can use the gas after two weeks of installation of the HDPE digester.

6.3 RESULTS FROM HDPE DIGESTER TESTING

The first HDPE digester was installed at the household of Mr. Pham Van Danh at Hoa An A hamlet - Thoi Hoa ward - O Mon district - Can Tho city. This 8 m^3 HDPE digester was applied to treat the waste of 25 pig herds with average weight around 50 kg each herd.

6.3.1 Testing results from HDPE digester

To evaluate treatment efficiency of this HDPE digester, there were some milestones of the sampling as presented in Table 6.1.

Table 6.1 The milestones for HDPE digester testing

Work	Jul-4	Aug-4	Aug-11	Aug-18	Aug-31	Sep-5
Digester installation	×					
Input discharge		×				×
Output discharge		×				×
Biogas		×	×	×	×	

The inlet and outlet discharge samples were taken at the time of washing the pigpen. While the outlet sample was directly collected from the outlet pipe of the digester, the collected inlet sample was a response to the mixing ratio of pig manure and washing water. The wastewater samples with typical parameters as shown in Table 6.2 below.

Table 6.2 The analysis results of the inlet and outlet discharges

No.	*Parameter*	*Unit*	Aug-4		Sep-5	
			Input	*Output*	*Input*	*Output*
1	pH		7.23	6.71	7.25	6.95
2	Alkalinity	mg/L	950	1870	3800	1560
3	TS	mg/L	3310	1632	8700	4600
4	VSS	mg/L	3020	1580	4240	2620
5	BOD_5	mg/L	-	-	825	405
6	TKN	mg/L	1316	483	588	420
7	Total Coliform	MPN/ 100mL	4.6×10^7	1.5×10^6	9.3×10^6	4.6×10^6

Note: "-" no data due to failure of lab equipments

The results showed that there was a good condition for anaerobic fermentation inside the HDPE digester. According to Gerardi (2003), digester stability is enhanced by a high alkalinity concentration of optimum value 1,500 ÷ 3,000 mg $CaCO_3$/L that serves as a buffer to maintain pH in range of 6.6 ÷ 7.6. It was observed that both of the recorded pH and the alkalinity were within this optimum range for biogas production in this study.

For the biogas composition, CH_4 was recorded only 32.1% in the first test. The reason of this low values because the test was processed only one month after the installation and operation of the HDPE digestion, and within this month the farmer did not use biogas for any purposes. As instructed in the HDPE digester installation guideline, at first natural air must be pumped into the digester so this natural gas did not totally release yet. That caused low methane but high other gas contained in the biogas composition.

From the second test onwards, the CH_4 value raised and kept stable from 56.3 to 57.2% that showed good quality of the biogas. In these tests, oxygen was still available (from 0.43 to 1.80%) because the digester was fed twice a day, and oxygen could mix inside the feeding and go into the digester together with the feeding. From now on the generated biogas was qualified not only for cooking but also for lighting at this farmer's household.

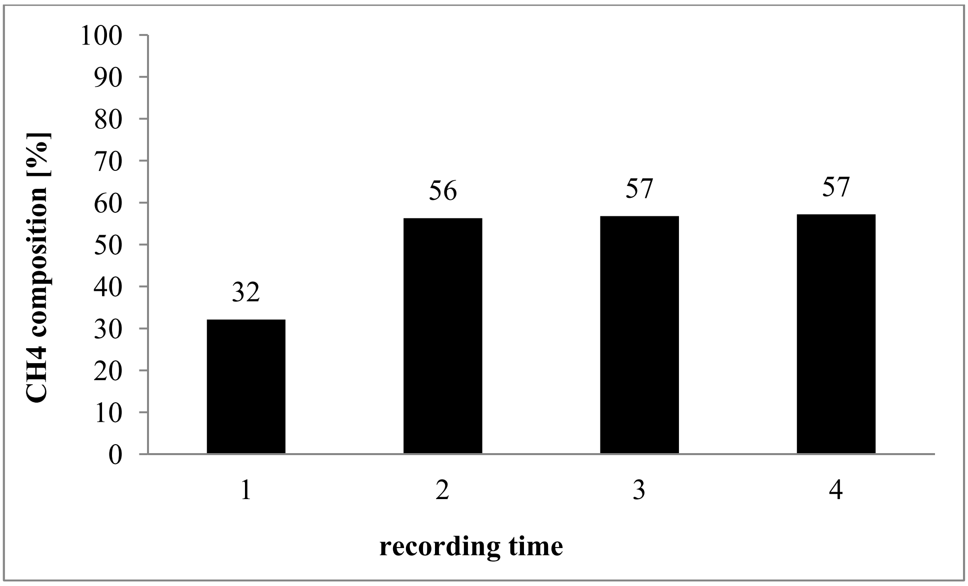


Fig 6.2 The biogas composition recorded from the HDPE digester

6.3.2 Testing for gas storage

Besides its disadvantages such as short lifetime, more risk, and low gas pressure, a PE digester has another weakness, that is a risk of gas leakage from its gas-bag. By testing in lab scale, after 3 days, more than 50% of the biogas loses from the PE gas-bag. The PE layer thickness of 0.20 ÷ 0.25 mm and its structure could be the reasons of the gas loss. On average, the volume of the installed gas-bag is about 5.5 m³. It is estimated that there will be 30% of the gas lost when the gas-bag is full after one day, it means that about 1.65 m³ biogas releases into the air in one day from each PE digester. According to Duong and Le (2002), there were more than 25,000 PE digesters installed in the South of Vietnam, it means about 41,250 m³ gas releasing into the air per day from this region. There should be a serious concern on dealing with such huge amount of biogas loss from PE digester.

HDPE layer was selected to be used as material for the new design of biogas plant in this study. There are various HDPE brand names but for the first digester testing, the GSE lining of 0.75 ÷ 1.0 mm thicknesses was used. According to advanced technical parameters of HDPE material, the air resistance of HDPE digester will be good and it can limit a loss of biogas which happens to a PE digester. The testing result on gas leachability from 0.75 mm thick HDPE lining is displayed in Figure 6.3. The biogas lost for the first 3 days less than 5% of the total volume and not extends more than 10% for the first 10 days.

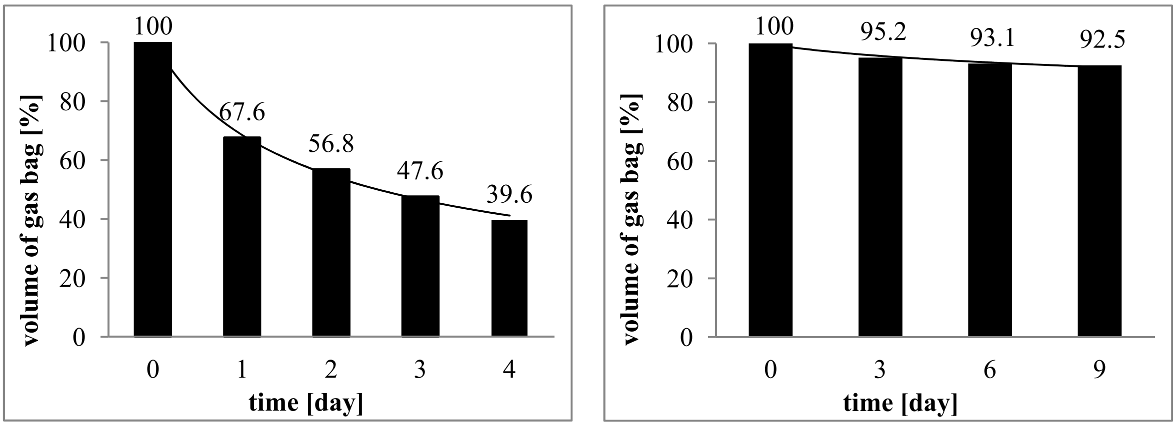


Fig 6.3 Gas remain by time in PE gas-storage (left) and in HDPE digester (right)

In fact, HDPE products are made from high qualified highly-density polyethylene resins. For these resins, carbon black, antioxidants, and UV stabilizers are added to assure long-term performance and UV resistance even in exposed conditions. The absence of leachable additives and fillers to HDPE products allow them to maintain excellent resistance to brittleness that may occur over time.

6.3.3 Comparison on installation cost of digesters

As acknowledged from the farmer's survey, investment cost is one important factor affecting farmers' decision on installation of a biogas plant. In the MD, among the existing digester models available presently PE digester offers the lowest investment cost but its lifetime is also the shortest, while other concrete plants require higher investment cost (from 5 to 6 times higher). Because of the mentioned disadvantages of the prevailing biogas plant models and the actual need of biogas application in the practice, there is a need to seek for a new digester model that could fix the gap between PE digesters and concrete plants.

Table 6.3 showed the estimated cost to install some of common biogas plant models in the MD. The estimates of the construction cost was made in accordance to the normal size of each plant that is frequently installed at farming households, and then the construction price per cubic meter of each plant was calculated.

Table 6.3 Cost estimates of common biogas plant models in the MD*

No	Component	8 m³ HDPE	10 m³ PE digester	4 m³ EQ1 plant	4 m³ EQ2 plant	6.2 m³ KT2 plant	8 m³ TG-BP plant
A	***Digester materials***						
1	Cement PC40			585,000	715,000	1,300,000	1,625,000
2	Solid brick					1,700,000	2,550,000
3	Multi-cored brick			440,000	550,000		
4	Fine sand			160,000	160,000	320,000	160,000
5	Crushed sand						210,000
6	Stone 1 × 2 cm			270,000	270,000	270,000	540,000
7	Stone 4 × 6 cm			125,000	125,000	375,000	
8	Flour limestone						336,400
9	PVC pipe	238,400	238,400	59,730	464,500	298,000	298,000
10	Rolled iron				77,500	77,500	93,000
11	HDPE layer			225.000			
12	PE gas storage		260,000	100,000	100,000		
13	PE for digester		660,000				
14	Bolt ϕ18 mm				15,000		
15	Crank handle				450,000		
16	Protect system		1,000,000				
17	HDPE digester	3,600,000					
B	***Biogas appliances***						
1	Biogas stove	240,000	100,000	240,000	240,000	240,000	240,000
2	Gas pipe, valves	250,000	250,000	250,000	250,000	250,000	250,000
3	Biogas lamp	120,000		120,000	120,000	120,000	120,000
C	***Labor cost***						
1	Land-digging cost	400,000	400,000	300,000	300,000	500,000	600,000
2	Construction cost		200,000	1,600,000	1,600,000	2,480,000	3,200,000
	Total in VND	**4,728,400**	**3,108,400**	**4,129,955**	**5,317,000**	**7,810,500**	**10,102,400**
	Cost [€/m³]	**22.5**	**12**	**39.2**	**50.5**	**47.9**	**48.1**
	Needed labor time [hours]	**59**	**31**	**103**	**133**	**126**	**126**

*Note: * - this cost based on the construction unit price in Can Tho city in September 2010*

Based on the results of cost estimates for biogas plants construction, the highest cost pertains to EQ2 biogas plant which has been developed by the scientists from Cantho University but it can apply to ferment both the livestock waste and biomass. This is only a kind of digester installed with crank handle to mix the internal substrate. The second expensive investment cost is both KT2 and TG-BP plants which require skilled labors to install them. The next one is the EQ1 plant but this model cannot clean sediment except break a hole on the digester body and it needs a PE bag for gas storage. The cheapest one is PE digester but this model has weaknesses related to lifetime and biogas appliance. The new model of HDPE digester appears to help fix the gap between PE digester and other concrete plants. The investment cost of HDPE digester is double price of PE digester but only around half price of concrete plant.

Another advantage of HDPE digester is high gas pressure which makes biogas applicable not only for cooking but also for lighting, saving farmers on energy expense. Such strength can be also found to fix-dome plants but not to PE, EQ1 and EQ2 digesters which store gas in extra PE bag. Farmers in rural Vietnam now pay more attention on applying biogas for lighting due to a common shortage of electricity in dry season and high price of electricity end-use in the rural areas. Hence, due to its strength in high gas pressure, the HDPE digester could be a promising innovative design to meet the demand on lighting for the farmers in rural Vietnam.

As regards the estimates, comparing the new HDPE digester to other common digester designs available in the MD, this HDPE model ranks only lower than the fixed dome plants but higher than the concrete plants with PE gas storage as well as PE digesters. However, it is worth noting that it should be necessary to have longer research to prove the confidence of the new HDPE digester model.

6.4 CONCLUSIONS

Based on the knowledge of biogas production in the MD, a new model of biogas digester was designed using HDPE material and having been introduced to farmers. A HDPE digester was implemented and installed onsite at Mr. Pham Van Danh's household in Hoa An A hamlet - Thoi Hoa ward - O Mon district - Can Tho city as a testing model. Some input - output wastewater and biogas samples were collected to test for digester quality. The testing results showed that this HDPE digester seems to be moderate on treatment efficiency and produced good quality of biogas.

After one and half month of the installation and operation of this HDPE digester, the farmer could apply the generated biogas for his domestic cooking and lighting in good condition. Mr. Pham Van Danh expressed his high satisfactory on the installation of the digester. He happily said, "We spent a little money but we get more benefits from the HDPE digester. From now on the wastewater of our piggery will be treated by this digester and our neighbors will not complain anymore about this pig dung. We have gas for cooking and lighting, which saves us money on liquid petroleum gas and electricity". He also informed that many people came to see his biogas digester and they showed their great interest in this model.

By our knowledge, up to now HDPE material is used for anaerobic digester but in form of biogas pond in which HDPE play the role as gas storage at upper part of pond. Normally the biogas pond applies to treat wastewater from industrial sector with high investment cost, not for agricultural sector where poor farmers can seldom afford this technique. Actually, a few years ago in the MD, HDPE material was so expensive and no equipment to weld HDPE layer to form of tubular so that nobody thought of applying HDPE digester to treat livestock waste in rural areas. The study made the first introduction of HDPE digester model to farmers in the MD. The investment cost of the introduced digester is double price in comparison to that of PE digester but only about half price of concrete biogas plants.

Compared to PE digester, the HDPE digester is easier to install. HDPE is durable material so that farmers have no problem when installing this digester. The HDPE digester can be located at any surface, while the PE digester needs a smooth surface to install. The installation of the HDPE digester is much quicker than others because farmers do not need to tie the mouth of PE tube into inlet and outlet pipes and do not need to insert the PE tubes to form triple system. The produced biogas can be stored inside the HDPE digester instead in a separated PE bag as required in PE digester. A big improvement of HDPE digester is the limited loss of biogas from digester system compared to PE digester.

In addition, due to the durability of the HDPE material, farmers are easy to use the electricity pump to empty the digester for cleaning procedure. Besides that, the HDPE digester can be easy to move from place to place. It is therefore convenient for farmers to operate the HDPE digester than the PE digester. In parallel, in case any defects happen on the HDPE digester, it is easy for biogas users to fix these holes by the pre-supply materials while the PE digester could not fix the hole.

Looking through the Vietnamese legal framework, there are few specific standards on small size biogas plants but Decision No. 21/2002/QĐ-BNN dated March 21st 2002. However, these standards only stipulated for the concrete biogas plants but not for biogas plants made from other materials. To ensure for quality of biogas plant that made from other materials, the government should issue some kind of quality control certificates for biogas plant before its distribution into markets. Such kind of certificate should be applicable not only for biogas plant but also for any biogas productions (biogas stove, biogas lighting, biogas power generator, etc.).

This is the first HDPE digester installed in the MD. However, before putting this model on wide scale, there should be further research on this digester. It still needs some funds to install more HDPE digesters at farming households so that this model can be evaluated in depth. Only after having more positive results of this type of HDPE digester, this HDPE digester model should be promoted to farmers in the MD.

CHAPTER 7. CONCLUSIONS AND OUTLOOK

7.1 CONCLUSIONS

Although Vietnamese Government has implemented a number of policies to improve the clean water supply and sanitation in rural Vietnam, the current clean water supply and sanitary conditions in the MD has not been improved as much as expected. Together with the growth of the industrial sector and population, increasing aqua-agriculture activities have made serious impacts on the water quality and sanitary condition in the MD. Improving the prevailing situation concerning water supply and sanitation in the MD should be the responsibility not only of the central government and local authorities but also of the local people. With respect to the real situation of the MD, local communities could contribute to the improvement of the sanitary conditions by participating in a VACB farming system instead of VAC system. It is therefore necessary to promote a widespread application of biogas plants in the area to address the mentioned problem.

In order to have an understanding of the current situation of biogas application in the MD, a survey was conducted in three representative sites located in Can Tho, Hau Giang and Dong Thap with the total participants of 117 households. The survey showed that the wastewater and waste from domestic and livestock activities has largely attributed to the serious water pollution and poor sanitary conditions in the rural areas of the MD. The local people commonly discharge their wastewater into open sources without any pre-treatment. More than 70% of the biogas users at the study sites reported that they had directly disposed of wastewater from livestock husbandry into open water sources before their installation of digesters, and 62% of the non-biogas users do so. Such a common practice is a serious threat to the local environment and public health. Installation of biogas plants is possibly important for the prevention of such a practice, improving the sanitary condition in the area. Actually, a relatively large proportion of the local people is aware of the benefits of biogas plants and has a demand for installation of biogas plants. 48% of the non-biogas users at the survey areas recognize biogas technology and its benefits, and over 50% of them would like to install biogas plants.

However, the biogas plant application is restricted in the area due to several reasons. One of the main reasons is that the cost of biogas plant construction is unaffordable to several farmers. 80% of the surveyed non-biogas users can not afford biogas plant installation, and more than 70% of the surveyed biogas users constructed their biogas plants with the financial support of some biogas projects. Another major reason is lack or shortage of input materials to biogas plants while there are no available additional or alternative input materials. There were 12% of the surveyed households explicitly complaining about the shortage of biogas produced by their biogas plants due to lack of pig manure. In practice, the possibility of a decrease in pig herds is significantly high in rural Vietnam. Since 2007 Vietnam has suffered from serious blue-ear pig diseases, affecting livestock raising throughout the country. In addition to the pig diseases, the instability of pig market possibly causes a temporary discontinuity in biogas operation and consequently affects the production of biogas by biogas plants. Furthermore, there are some impediments in the existing biogas plant models, reducing the attractive advantages of biogas application to the local people.

In attempt to seek for a solution for lack or shortage of PM as an input material for biogas plants, this study implemented experiments on the co-digestion of PM+WH and of PM+SMC. Both of WH and SMC are extensively available in the local MD, but they are reputed as hard treatment wastes. Mixing PM and rich carbon materials helps reach the optimal ratio of the C/N in the mixture and the mixture can remain in good conditions for an anaerobic process. As regards the batch experiments of co-digestion of PM and WH, the result of the experiments indicated that the more percentage of WH is available in the feeding rate, the more biogas will be produced. The WH used in the experiments included stems and leaves without the root so as to avoid contaminated metals releasing into the digesters. Based on the ODM values, the treatments of 25%PM+75%WH and that of 0%PM+100%WH produced significantly more biogas than the treatments of 100%PM+ 0%WH, of 75%PM+ 25%WH and of 50%PM+50%WH. The produced biogas was in good quality with methane reaching from 46% to 60%. The finding clearly showed that WH is potentially an additional input for co-digestion with PM in biogas plants. Even it is largely possible for farmers to apply only WH into their digesters, which still produces more biogas. The findings lead to the conclusion that WH can be used not only as an additional input but also an alternative input in biogas plants in the MD.

In line with the success of the experiments on the co-digestion of PM and WH, the batch experiments of the co-digestion between PM and SMC showed positive results. Based on the ODM values, the produced biogas was not significantly different between the treatments of 100%PM+0%SMC, of 75%PM+25%SMC, of 50%PM+50%SMC and of 25%PM+75%SMC. That means in case of lack of PM, farmers can use SMC up to three-quarters of the total input supplied to the co-digester and the biogas yield is the same as the case of 100%PM supplied to the digester. The produced biogas was in good quality with methane reaching from 49% to 56%. SMC can be applied as a tolerable material in the co-digestion with PM in the biogas plant. If doing so, farmers can take advantage of the residue of their eco-farming system instead of wasting them around their living place as they currently do.

In parallel, the lab-scale semi-continuous treatments of 75%PM+25%WH and that of 75%PM+25%SMC were implemented to test the loading rate. WH and SMC are hard to be digested inside a digester because of high carbon and lignin contents. However, by testing for a 90-consecutive day period, these experiments were operated well without blockage. Some of the control parameters such as pH and alkalinity were in an optimal range of anaerobic process. In both of the co-digestion treatments, the average methane contained within the biogas was 60%.

According to the results from the co-digestion testing, the mixture of pig manure and biomass used as a feeding material into the digester not only maintained the produce of biogas but also improved the quality of the bio-slurry from the digester. In fact, adjusting the C/N ratio in the feeding resulted in a good structure of substrate that is possibly used as an organic fertilizer to fishponds or for gardening. The testing of application of the bio-slurry to planting leaf mustard vegetables was processed in lab-scale pots. Compared to the experiments of planting leaf mustard vegetables by inorganic fertilizers, the growth rate of the mustard in the experiments with the bio-slurry from PM+WH co-digester was not significantly different, but the growth rate in the experiments with the bio-slurry from PM+SMC co-digester was significantly higher. Besides that, supplied with bio-slurry from co-digesters, the leaf mustard plants started to flower from the 35th day. In other words, the leaf mustard fertilized by the bio-slurry is ready to be harvested after 35 days of planting while the life cycle of leaf mustard is normally around 40 to 45 days. The finding showed that the bio-slurry from co-digesters helps not only increase the productivity of leaf mustard vegetable but also reduce the cultivation time thereof. Another benefit coming from applying the bio-slurry for gardening is an improvement in soil structure. The soil analysis clearly showed that the bio-slurry from co-digester performed better than the bio-slurry from digester with a single feeding material. Actually, the co-digestion materials help recovers soil structure improving its aeration condition and adjusting the C/N ratio. As a result, plants easily take up the nutrients from soil layers.

The testing of application of the bio-slurry into fishpond was conducted at farmer households with Tilapia fish raising. The result on fish weight recorded in a 52-consecutive day period revealed that the fish raised with the bio-slurry grew significantly better than the fish raised without the bio-slurry. There was no significant difference in fish weight between the fish raised with the bio-slurry from co-digester PM+WH, PM+SMC and from the digester solely inputted by pig manure. In addition, the bio-slurry applied into the fishpond could increase the nutrient content essential for the development of algae and zooplankton. The water body became dark, a signal of density of algae availability which is beneficial for the fish. It is noticed that even though the bio-slurry diluted with water column in the fishpond, the water quality of the fishpond did not go beyond the Vietnamese standard on wastewater discharge. Therefore, in case farmers refresh water in their fishponds, it is sanitarily acceptable to re-use the water taken from the fishponds for gardening or orchard irrigation instead of disposing it into open water sources.

Given the current application of biogas technology in the MD, the popular biogas models are PE, TG-BP, KT2, EQ1 and EQ2. However, the model with cheap investment cost has short life-time and risky, while the models with long life-time and stable operation are much more expensive. To minimize the weakness of the existing biogas plants, this study designed a new HDPE digester and onsite tested it at a farmer's household. Compared to the existing biogas plant models, this new digester is simple on installation, acceptable on treatment efficiency, effortless on operation and reasonable on investment cost. In fact, in contrast to the PE digester on which the design of this HDPE digester is based, the new digester is already pre-manufactured in a factory and it is easy to be packaged in compact form and transported to installation sites. In addition, the new digester model is able to be installed on any surface without any special arrangement. More importantly, this digester is easy to fix; therefore, farmers themselves can manage to fix holes (if any occurs to their digesters) by pre-supply materials in a simple way. Unlike the PE digester which needs a separated PE bag to store biogas, the biogas produced from the HDPE digester is stored inside the digester body, thereby helping increase the gas pressure for lighting purpose. The HDPE digester has plenty of considerable advantages over the PE digester, but its investment cost is double compared to that of the PE digester. However, with almost similar lifespan, the HDPE digester costs only around half the price of the concrete models. Given its strengths relative to the other types of biogas plants presently available in the MD, the HDPE digester could be an optimal biogas plant model for farmers in the MD to apply into their farming system in order to treat waste and wastewater from both domestic activities and livestock raising.

In summary, the study found that water hyacinth and spent mushroom compost, two of the local materials available in the MD, are highly possibly applied as additional feeding materials to pig manure into the biogas plant. The co-digestions can maintain the yield of biogas volume in both cases of co-digestion and even increase biogas volume in the case of mixture of pig manure and water hyacinth. The finding is crucially significant to the improvement in the application of biogas technology in the rural MD in particular and the promotion of biogas development in general. Farmers have choices of input supply to their biogas plants, reducing their complete dependence on pig manure as a sole input to biogas plants. Additionally, it will help to address the blockage of waterway by water hyacinth due to its fast growth and the environment pollution caused by the unregulated release of the residues from mushroom cultivation in the local areas if water hyacinth is used as additional feeding materials in practice. Furthermore, the study implies a recommendation concerning an improvement in water waste treatment in the VACB farming system. Because the effluent from the co-digestion is below Vietnamese standards on wastewater discharge, it can be sanitarily acceptably re-used as feeding to fishponds or watering to gardens, which is considered as a second treatment step. By the two-step treatment, the wastewater is simply recycled in a closed system, avoiding pollution to open water sources. That means biogas technology is useful for improvement of wastewater quality and recovery of nutrients to aqua-agriculture production.

7.2 OUTLOOK

The success of promotion of biogas technology development on a wide scale in the MD will be attributed to several factors. Besides some technical and socio-economic issues as analyzed in this study, a systematic and comprehensive evaluation of the biogas development as well as a strong legal framework on biogas management should be developed to facilitate the extensive biogas application over the rural areas of the MD in particular and of Vietnam in general. Among the Vietnamese regulations on renewable energy, only two legal documents stipulate the biogas sector exclusively. The first regulation is Decision No. 21/2002/QĐ-BNN issued by Ministry of Agriculture and Rural Development [____, 2002] which provides eight specific standards on small-sized biogas plants. The second regulation is Decision No. 1380/QĐ-BNV issued by Ministry of Home Affair to establish the Vietnam Biogas Association - VBA [____, 2010]. However, these two regulations deal little with the development of biogas technology in Vietnam, particularly no regulations on development strategy and plan for biogas plants. Meanwhile, such a development plan is available for bio-fuel (Decision No. 177/2007/QĐ-TTg on Strategy for bio-fuel development to 2015 and vision 2025) or wind energy (Decision No. 37/2011/QĐ-TTg supporting mechanism for the development of wind power project in Vietnam). There is a need to improve the legal framework for biogas development in Vietnam to support the application of biogas technology to environment protection more effectively and economically.

In addition, because a number of farmers in rural Vietnam normally lack capital to invest in biogas plant construction, the central and local government should provide farmers some financial support to encourage their investment in biogas plants. Some advanced countries on biogas technology have had good experience related to such kind of support. For example, in Germany, under the national environment protection and energy saving program, low-interest loans are available for investment in small-scale biogas system, and the Renewable Energies Act offers subsidy scheme for biogas system operators [Poeschl *et al.*, 2009]. In Denmark, biogas plants are exempted from tax which is imposed on heat sales and receive investment grants of about 20% [Sannaa, 2004]. It is also worth recommending that the staff of a biogas plant project should introduce various biogas plant models to farmers instead of only one model as it has done. In fact, within the biogas projects, only one type of biogas plants were introduced to the beneficiary farmers and the farmers had no choice for the digester type which they are interested in. The reason why there is only one digester model offered to all beneficiaries within one biogas support project could be to simplify the management work of biogas plant construction. However, such the offered models could affect farmers' interest in biogas technology, particularly in cases where the offered digester are not suitable to farmers' specific situations and needs.

In Vietnam there is at present an organization focusing on promotion of development of biogas technology that is VBA established on April 09^{th} 2011 [VMHA, 2010]. Through the VBA, the new biogas plant model could be introduced and get feedback, then improve it in positive way. Further, to promote the new biogas plant model successfully, it is suggested to take an example of a successful model "biogas shop" introduced in Thanh Hoa where the Vietnam Garden Association established a network of biogas shops at every ward. This is a good way to introduce and advertise new products directly to farmers in Vietnam.

Besides that, it is necessary to have a study on life cycle assessment (LCA) to evaluate the environmental effects of biogas production by comparing some critical factors to reference systems. In comparison to the biogas plants benefiting from heat sale or electricity generation in Western countries, the product chain of biogas in the MD is not too complicated. Obviously, by small-scale biogas plants attached to farms, the produced biogas is mainly used for cooking and only small portion for lighting. By using a computational model, the energy supply from biogas will be calculated and compared with a fossil energy system. Some LCA studies were processed by computational model by Bachmaier (2010) and Pucker (2010). Furthermore, by integrating a biogas plant to the VACB farming system, it is possible to submit for a Clean Development Mechanism (CDM) project. According to Yapp (2005), CDM is one strategy under Kyoto Protocol offering a timely chance to overcome barriers which limit the biogas development on technical, financial, institutional and policy, social and entrepreneur aspects. CDM projects could therefore be a promising solution to develop biogas technology.

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APPENDICES 1. EXPERIMENTAL PICTURES

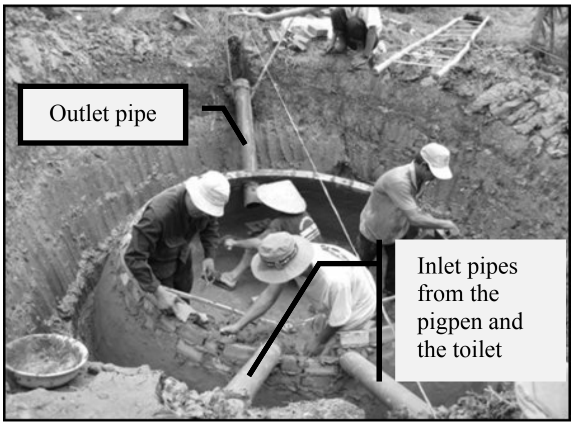
Pic 1 WH blocked waterway in the MD

Pic 2 Residue of SMC

Pic 3 Experiments of Tilapia fish raising

Pic 4 Experiments of leaf mustard planting

Pic 5 Sky-toilet at farm household



Pic 6 Biogas plant combined with toilet

Pic 7 HDPE digester (left) and its easy package for transportation (right)

Pic 8 Inlet/outlet of HDPE digester (left) and connect to pipes by adjusting ring (right)

Pic 9 The HDPE located at the installation site (left) and when it's full (right)

APPENDICES 2. SUMMARY OF QUESTIONAIRE SHEETS

App 2.1 USER BIOGAS QUESTIONAIRE

House code: ………………………………………… Date of interview: ……/……/2010
Name of respondents: ……………………………………………… Age: …………………….
Sex: ☐ Male ☐ Female
Education level: ………………………………………………………………………………
Province: …………………………………….. District/Town: …………………………………….
Commune: …………………………………… Village: ……………………………………………

1 General information

1.1 Characteristics of respondents

110 Name of the family head ………………………………………………… Age ………….

111 Sex of the family head

112 Main occupation of the family head

113 Family size (number)

114 Education status of respondent's family (from 6 years old only)

115 Type of house

116 Whether household is connected with electricity

117 Valuable assets

1.2 Identification of biogas plant

120 Type of biogas plant

121 Capacity of biogas plant

122 Time of starting construction

123 Time of starting operation

124 Name of biogas company

125 Investment cost of the biogas plant (state in VND)

126 Investment source of the biogas plant (state in VND)

2 Biogas digestion information

2.1 Installation of biogas plant

210 Before installation, how do you get knowledge on biogas plants (tick one)

211 The reasons of biogas plant construction (rank the priority reasons if any)

212 Who give you advice on selecting the biogas dimension (tick one)

213 Why you select the place to build the biogas tank (rank the priority reasons if any)

214 Did you supervise the building work

2.2 Using of biogas plant

220 Are you satisfied with the plant dimension

221 Were there any problems during the biogas operation

222 Which part of the plant had the problems

223 In case of problems, do you think the reasons are…

224 In case of repair, how much of money you spent last year ………………………………VND

225 Did the biogas plant stop producing gas sometimes

226 Why did the plant stop producing gas

2.3 Biogas plant feeding

230 How many times per day dung is fed into the plant (tick one)

231 Do you fill all residues to the plant

232 If not, what could be reasons

233 In that case, how did you do with untreated residues from your livestock

234 How water is used for pen washing and how much

235 Additional water required after installation of the plant

236 Usually who feeds the biogas plant

2.4 Maintenance information

240 How has your livestock number changed before and after the biogas plant installation

241 Do you apply any kind of gas treatment

242 Besides manure, did you add any material into your biogas plant

243 What kind of food do you feed livestock

244 What kind of maintenance work did you do

245 Have you noticed gas leaking from plant/pipe

246 How do you find out about gas leakage

247 What did you do to stop gas leakage (tick one)

248 How many times did the gas leakage happen last year

249 How much do you have to pay to fix the problem

2.5 The sale services from biogas builder

250 Did the biogas plant reach any problems within its warranty time

251 Had you been received timely repair services from biogas builder

252 How promptly the company provide services after you lodge a complaint (tick one)

253 Had you received any training from the biogas company

254 If yes, on what

255 Which person of your family had been trained

256 Can you undertake the repair and maintenance of plant by yourself

257 Did the company give any visit after the installation of the biogas plant

258 The frequency of visit

259 Had the company recommended any device to treat the odor of the gas (H2S)

3 Biogas application

3.1 Energy sources

310 What type of fuel did you use before biogas plant construction

311 What type of fuel do you use as substituted besides biogas after building the plant

312 Who and when to collect the fuel (wood, rice straw…) before installation of the plant and how about now

312 Is the gas sufficient (tick one)

313 What did you do to increase gas production

314 Who is the main cook in your family before and after installation of the plant

315 Has any member in your family suffered from fire accident during the last 12 months

316 If yes, who were they (state the number)

3.2 Use of biogas

320 Number of biogas stoves

321 Daily consumption of gas for cooking (hour)

322 Are you satisfied with cooking with biogas

323 If not satisfied, the reasons are (tick all that apply)

324 If fully satisfied, the reasons are (tick all that apply)

325 Number of biogas lamps

326 Daily consumption of gas for lighting

327 Are you satisfied with lighting by biogas

328 In case of not satisfied, what are the reasons (tick all that apply)

329 In case of fully satisfied, what are the reasons (tick all that apply)

4 Impact of biogas installation

4.1 Life conditions

410 Have you constructed toilet at your house

411 Is the toilet connected to the biogas plant

412 Why you connected toilet to the biogas plant

413 Why you did not connect toilet to the biogas plant

414 Treatment of the livestock manure before installation of the biogas plant

415 Number of your family members get illness and disease in the last 12 months

416 How much time do you save after installation of the biogas plant

417 How is the saved time used by your family members

418 Is the saved time used for any production works

419 If yes, what type of works

4.2 Use of biogas by-products

420 Do you use the slurry manure

421 The reasons why you do not use slurry manure (tick all that apply)

422 How do you do with the un-used slurry manure

423 Why do you use the slurry manure (tick all that apply)

424 If you use the slurry manure, in what way do you use it

425 How change in use of manure and fertilizers

426 Changes in land scale after the biogas installation (state the dimension of change)

427 Changes in crop productivity by land category (state any examples, if possible)

428 Do you apply slurry into fish pond

429 Expense on food for fish pond (VND/year)

5 What are your suggestions to improve the overall performance of the biogas plant

Signature: ………………………………..

Name of interviewer: ……………………………………………………

App 2.2 NON-USER BIOGAS QUESTIONAIRE

House code: ………………………………………… Date of interview: ……/……/2010
Name of respondents: ………………………………………………… Age: …………………….
Sex: ☐ Male ☐ Female
Education level: ……………………………………………………………………………………
Province: …………………………………….. District/Town: …………………………………….
Commune: …………………………………… Village: ……………………………………………

1 General information

1.1 Characteristics of respondents

110 Name of the family head …………………………………………………… Age ………….

111 Sex of the family head

112 Main occupation of the family head (tick one)

113 Family size (number)

114 Education status of respondent's family (from 6 years old only)

115 Type of house (tick one)

116 Whether household is connected with electricity

117 Valuable assets

1.2 Production activities

120 Kind of livestock raising at home and unit number

121 How frequency of livestock raising

122 What kind of food you feed livestock (state the quantity of the food)

123 Treatment of the livestock manure

124 How much is your income from raising livestock

125 How is your land categories

126 How much of fertilizers do you use for each crop

127 Do you apply slurry to fish pond

128 Expense on food for fish

1.3 Living activities

130 Which kind of activities offers the main income in your household

131 Is there toilet at your household

132 Kind of toilet at your household

133 What type of fuel do you use

134 Who and when to collect the cooking fuel

135 Who normally cooks in your household (state how long it takes to cook for each meal)

136 If yes, who are they (state the number)

137 Number of your family members get illness and disease in the last 12 months

2 Biogas digestion information

2.1 Awareness on biogas plant

210 Are you aware of the biogas technology

211 If yes, how did you know about this technology

212 Could you give 3 main advantages of biogas plants

213 Could you give 3 main disadvantages of biogas plants

214 What are the reasons for not installing a biogas plant

215 Would you like to adopt a biogas plant

216 If yes, why (state 3 main reasons)

217 What kind of supports do you expect from government/project to give you for installation of a biogas plant

218 If no, why (state 3 main reasons)

219 Do you know any information about supporting programs from the government on biogas installation

2.2 Please give your opinions on biogas plants

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Signature: ………………………………..

Name of interviewer: ……………………………………………………

App 2.3 BIOGAS BUILDER QUESTIONAIRE

Respondent code: ……………………………………………… Date of interview: ……/……/2010
Province: …………………………………….. District/Town: …………………………………….
Commune: …………………………………… Village: ……………………………………………

1 General information

1.1 Characteristics of respondents

110 Name of respondent ………………………………………………………… Age …………..
111 Sex of the respondent
112 Education level
113 Family size (number)
114 Your occupation before becoming a biogas builder …………………………………………
115 Current occupation ……………………………………………………………………………..

1.2 Biogas builder's information

120 Position in the builder team
121 How many people are there in your team
122 Did you attend any training course on biogas technology
123 What training course on biogas technology did you attend
124 What is your opinion on the content of training program
125 How much is your daily wage for biogas building ………………………………. VND/day
126 Compared to other jobs
127 What is the main reason that you start working on biogas construction
128 Do you enjoy the work of biogas construction
129 How many biogas plants have you built

2 Biogas plant information

2.1 Preparing for construction works

210 How to approach to the head of the household
211 Choice of construction place
212 Who choose the construction place
213 What do you base on to determine the dimension of plant

2.2 The quality control

220 Building materials should meet the technical requirements
221 Do you strictly follow the design of the plant when you construct it
222 How did you solve the problems happening during the construction time
223 Did you test water-tight and gas-tight of biogas plant
224 Who installed the gas pipe and other additional appliances (stove, …)

225 Is there a main valve in gas pipe

226 Have you ever recommend the head of household for any gas treatment facilities (CO_2, H_2S)

227 Have you ever made any agreement with the household on warranty period of biogas plant

2.3 Maintenance, reparation works

230 Did you take part in repairing any biogas plant

231 The reasons for repairing

232 How was the reparation made

233 Results of the reparation

234 Did you guide the household how to feed the plant

235 Did you advice the household how many livestock they should maintain in their pigpen

236 Did you guide how to check the plant and what to do to make the newly-installed plant work

237 Did you show how to use bio-slurry

238 Did you show how to maintain the plant

3 Other opinions

3.1 From the households due to biogas construction service

310 Is the head of household satisfied with the constructed plant

311 The reasons of satisfaction

312 The reasons of not satisfaction

3.2 Comments from the biogas builder

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Signature: ………………………………..

Name of interviewer: ……………………………………………………